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«BALDIN AUTUMN» AND GAUGE FIELDS

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«Балдинская осень» и калибровочные поля

Данная статья представляет собой воспоминания участника событий о начале теории калибровочных полей и первой конференции из серии «Балдинская осень», состоявшейся в 1969 г. Конференция называлась «Векторные мезоны и электромагнитные взаимодействия». В то время единственным экспериментальным указанием на существование новых универсальных взаимодействий были процессы с участием векторных мезонов. Векторная доминантность была экспериментальной основой утверждения, что теория калибровочных полей имеет физический смысл. Со временем обсуждавшаяся тогда форма теории калибровочных полей получила общее признание и экспериментальное подтверждение. Это привело к построению хорошо известной Стандартной модели взаимодействий элементарных частиц.

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«Baldin Autumn» and Gauge Fields

The paper is the reminiscences of the participant of the gauge field theory beginning and the first «Baldin Autumn» conference in 1969. This conference was named «Vector Mesons and Electromagnetic Interactions». At that time, just the processes with vector mesons participation contained some experimental indications of new universal interactions existence. Vector dominance was the experimental evidence of physical reasons of the gauge field theory. In the course of time the gauge field theory form, which was under discussion thirty seven years ago, became generally recognized and experimentally corroborated. It led to construction of the well-known Standard Model of elementary particle interactions.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

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The most impotant moment of «Baldin Autumn» opening in 1969 in Dubna is that this not large conference regarded gauge field theory as fundamental physical theory. So experimenters must be interested in its testing. At that time a few predictions existed which arose directly from gauge field theory. One of such predictions was vector dominance which A. M. Baldin was occupied with.

The theory and experiment were weakly connected with each other because mathematical means of the gauge field theory were insufficient to calculate parameters of processes with elementary particle participation. Theoretical predictions had the quality nature and mainly concerned to elementary particle classification. By that time many new particles were discovered but fundamental principles permitting to clear up their interactions were absent.

Moreover, relation between internal and external symmetries remained unintelligible. Nobody succeeded in doing them having the same rights or in unification them in enough wide symmetry group. Mass spectrum of elementary particles did not also lend itself to explanation.

The way which Yang chose could seem to be strange. When Regge poles, bootstrap and variance ratios were leading and equations were undesirable in quantum physics, Yang decided to write some equations for weak interactions of elementary particles by analogy with Maxwell electrodynamics. The concepts chosen by Yang were already rejected.

Yang took Weyl's idea about gauge invariance in electrodynamics as the basis of his new theory of weak interactions. Weyl wrote: «... gauge invariance in electrodynamics in the same way corresponds to principle of electrical charge conservation as coordinate invariance corresponds to energy-momentum conservation law».

It is necessary to note that this analogy is only true until gauge and coordinate symmetries are global one and, hence, are described by finite Lie groups. In this case invariants of corresponding symmetry groups can be interpreted as a charge and energy-momentum of particle.

Finite-symmetry group transformations depend on number sets, i.e. constants. They correspond to the situation when the transformations (for instance, rotations) are simultaneuosly fulfilled by the same angle in all points of space–time. But such a situation cannot be realized experimentally in a whole large domain for finite light velocity. *Global symmetry contradicts relativism!* Therefore, relativistic theory must assume the transformations which parameters are depending on the points of space–time. This symmetry is named a local one.

Lie groups corresponding to a local symmetry belong to infinite Lie groups. These groups have not any invariants and conservation laws which are similar to the invariants and conservation laws corresponding to finite Lie groups and global symmetries. For this reason, until now, the General Relativity occupies isolated position between physical theories. Its symmetry group (i.e, general covariant coordinate transformations) is infinite Lie group. All gravitation energy-momentum problems follow from here.

In 1918, and later in 1929, Weyl used the local gauge invariance of electrodynamics as a principle permitting to put in a theory interaction with a vector field. This field Weyl identified with electromagnetic vector-potential. It seemed to him that in this way a connection between local gauge invariance and vector field existence was established.

In 1918, Weyl constructed the united theory of gravity and electromagnetism using two local invariance principles: local gauge invariance and local coordinate invariance of GR. He did not observe that local coordinate invariance of GR *does not generate* any vector field! Using local gauge invariance (more accurately, local scale invariance), Weyl introduced a vector field in addition to metrical tensor $g_{\mu\nu}$ and identified it with electromagnetic field. Really, Weyl theory did not unite GR and Maxwell elecrodynamics. Moreover, it was found incompatible with Einstein theory. It contradicted experimental data and was need in the non-Riemannian geometry. Einstein came out against Weyl's theory, and Weyl retracted it.

In 1929, without gravity questions, Weyl proposed to use the local gauge invariance principle in Dirac's electron theory. He showed that for local gauge invariance of Dirac's Lagrangian it is necessary to put in the theory a vector field, which transformation properties coincide with that of electromagnetic vector-potential. Scientific public regarded this Weyl's observation as elegant mathematical method which does not add any new information on electron.

In 1949, Yang met Weyl at the Princeton Advanced Studies Institute. They met from time to time until 1955.

Yang called his attention to local gauge invariance idea thanks to Pauli papers. But when in 1954 the paper of Yang and Mills was published, Pauli did not tell Weyl about it. Perhaps, Weyl could be glad. He beleived in local gauge invariance to the end of his days.

Unfortunately, it is not known how Einstein and Pauli perceived the Yang–Mills paper. General scientific public did not observed it. But in Markov–Baldin group the Yang–Mills paper was observed.

In the USSR instead of gauge fields it was used the term «compensating fields» corresponding with Weyl's mathematical procedure of vector field introduction. Compensating fields ideas spread thanks to the collection of papers in Russian «Elementary Particles and Compensating Fields» edited by Prof. D. D. Ivanenko in 1964. All basic papers on new direction in elementary particle physics were represented in this book.

The pupils of D. D. Ivanenko began to develop Utiyama and Kibble ideas with a view to get compensating treatment of gravitational field. This way led to many variants of non-Einsteinian theories of gravity with torsion and nonmetricity. These theories do not consistent with experimental data. Experiments only confirm Newton and Einstein theories of gravity.

Now the accepted Standard Model of elementary particle interactions is based on symmetry group $SU(1) \times SU(2) \times SU(3)$. Individually $SU(1)$ group corresponds with electrodynamics, $SU(2)$ group corresponds with weak interactions, and $SU(3)$ group corresponds with strong interactions. But in the Standard Model these interactions are mixed by symmetry group.

The Gauge theory of strong interactions (Quantum Chromodynamics) attracted intense interest of Russian scientists after publishing of my and V. N. Popov «Gauge Fields» monography in 1972.

«Baldin Autumn» came in summer of 1969 in Dubna when in the gauge field theory it was spring. New approach in elementary particle physics shot out.

In 1967, B. de Witt in the USA and L. D. Faddeev with V. N. Popov in Leningrad found the quantization method of gauge fields by path integrals.

At the same time (1967), I formulated variational formalism for infinite Lie groups and restated the classical gauge field theory in terms of infinite Lie groups representations. Weyl's compensating procedure became redundant. Therefore, I decided to call gauge fields as gauge fields in Russian. Simultaneously, geometrical interpretation of gauge fields was obtained by me in terms of fibre bundle space geometry. It was found that local coordinate transformations of GR correspond with $g_{\mu\nu}$ as gauge field. But they do not generate $g_{\mu\nu}$ just as local gauge invariance of electrodynamics *does not generate* real electromagnetic field. Interactions are classified by representations of infinite Lie groups just as elementary particles are classified by representations of finite Lie groups.

De Witt–Faddeev–Popov results cleared the way to study of elementary particle physics by the new methods of quantum gauge field theory.

My formulation of classical gauge field theory demonstrated fundamental nature of new theory. It permitted to use the local gauge invariance principles together with Einsteinian general covariance for construction of unified geometrical theory of all fundamental interactions *including GR!* So, the problem which Einstein and Weyl were occupied with during many years now is solved. It became possible thanks to appearance of new branches of mathematics.

In 1970 at Rochester conference in Kiev A. M. Baldin talk about my results to Yang. But Yang did never refer to it.

The first «Baldin Autumn» conference was opened by talk of L. D. Faddeev on gauge fields quantization and my talk «Geometrical Description of Compensating Fields ($\equiv$ Gauge Fields)» (both in Russian). Among the members of the conference were Prof. D. V. Volkov from Kharkov and Prof. S. C. C. Ting from the USA. In 1971, first of them proposed supersymmetrical approach to the theory of gauge fields. In 1976, the Nobel Prize for physics was awarded to S. C. C. Ting and B. Richter for their pioneering work in the discovery of heavy elementary particle of a new kind. These particles helped to corroborate correctness of elementary particle quark models.

I would like to finish with S. Weinberg's words from his book «The First Three Minutes»: «I do not think it is possible really to understand the successes of science without understanding how *hard* it is...».

Astonishing A. M. Baldin's property consisted in that he always saw things in their true light and at any troubled times he found optimal decision. He always knew what it must be done next.

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