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ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

CONCLUSION

(Summary talk on the reports submitted to the II International Symposium on Non-Local Quantum Field Theory, Azau, March 14-25, 1970).

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I would like to make some remarks of a general character concerning the Symposium.

I belong to the generation in which the modern theory of elementary particles, the modern quantum field theory, was born and developing. One would like to understand what was going on at the Symposium, in clarifying the situation in a historical aspect, namely what one attempted to achieve when the theory of elementary particles was at the stage of its origin, at what one has arrived at present, what are the further perspectives. Some remarks are of a personal character. The situation in theoretical physics bears a slight resemblance to the well-known joke about the madhouse where each sick man considers himself the only true Jesus Christ. All of us are ill with theoretic physics and it is doubtful whether the progress of the science as a whole is possible without fanatical belief of each in the validity of his ideas.

Obviously, I express the common opinion if I say that the Symposium has been successful. Although we are not leaving the Symposium with a consistent, divergence-free theory, nevertheless we are able to ascertain a partial success in attempting to construct such a theory; we can meet with open eyes forthcoming difficulties. Various ways of the development of field theory were discussed at this Symposium. Problems of nonlinear theory, nonlocal theory and, in particular, its form realized in the non-Euclidean geometry of momentum space were considered. Possibilities of the indefinite metric were also discussed.

All these possible ways of further development of the theory were discussed in the past, it should be said, in a relatively distant past, as well. So, the "age" of the nonlinear theory is reaching 60 years (G.Mie/1/, 1912). The relativistically invariant form factor is at a mature age, it is almost 40 years old (G. Vataghin/2/, 1934), its geometrical interpretation in momentum space (non-Euclidean geometry in the momentum space) is also more than 30 years old (M. Born, 1938). Moreover, the youngest theory, indefinite metrics, is almost a quarter of a century ... During these decades much work has been done along these lines, an immense number of articles has appeared and many of them have been presented at the Symposium.

It has been clarified over this time that all ways of overcoming difficulties connected with divergences lead to new additional difficulties which the traditional theory did not know. The work during several decades was devoted to the partially successful overcoming of numerous intrinsic difficulties of the formalisms under discussion. In other words, all these theories worked essentially for themselves as is often the case in a large, but not very successful business, following the well-known Parkinson's laws.

As is known, and as the work of the Symposium shows, most effort has been in developing the ideas of nonlocal theory, introducing into the formalism a relativistically invariant cutoff. At the very beginning of the development of this direction a question arose from what general principles the unambiguous expression for the form factor may be derived. The theory should be unambiguous. The problem of an unambiguous choice of the form factor remains unsolved after this Symposium, too.

As long as 30 years ago an attempt was made to formulate the idea of an extended source, more exactly, the idea of nonlocal, non-point interaction on the basis of the restriction of the field measurability in a small domain connected with the atomism of the electric charge[x] /3/. This restrictions on the field measurability were formulated by means of commutation relations between the field quantities (potential A) and the four-vector of the point (more exactly, coordinates of a test body)

$$A_{\mu} x_{\nu} - x_{\nu} A_{\mu} \neq 0 \ . \qquad (1)$$

Such a mean of introducing nonlocality is mentioned for the reason that on the one hand it is equivalent to the introduction of a ceratin relativistically invariant form factor, from the other hand, it is possible, using (1), to calculate directly the commutator $[A(x), A(y)]$ which, as it turned out, does not vanish on the space-like surface. So, it was first established that in nonlocal fields the causality principle is violated. Further work in this direction was associated with the nonlocality form which is defined by direct introduction to the theory of various form factors and becomes the main problem of the construction of the appropriate S -matrix formalism of the theory. It has also been clarified that in nonlocal theories there arise difficulties connected with unitarity, gauge invariance and the construction of the T -product in the S -matrix formalism.

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[x] According to the analysis of quantum electrodynamics given by Bohr and Rosenfeld, the latter in its modern form assumes the measurability of the electromagnetic field in an arbitrary small domain which in turn assumes the existence of test charges localized in an arbitrary small region with an arbitrary large electric charge. The main idea of the article quoted consists in that the formalism of the modern electrodynamics is thus in contradiction with the charge atomism and that the account of the latter leads to another electrodynamics where the restrictions of the field measurability in small regions make meaningless the corresponding integration of the quantities leading to divergences just when integrating over the volume near the origin (i.e. near the charge). It should be stressed that the problem as to what restrcitions on the field measurability are imposed by the charge atomism and how the quantum electrodynamics formalism is to be modified with the account of the charge atomism is as yet still open.

It is interesting that many difficulties were turned out to be common for different attempts of the construction of a theory without divergences. It was found out gradually (a number of reports was devoted to just this problem) that difficulties with unitarity and gauge invariance in electrodynamics for nonlocal theories can be overcome[x/]. But there remains one fundamental difficulty, carefully speaking, one fundamental difference of the nonlocal theory from the traditional theory, the local one. This is the violation of causality which is revealed in that the corresponding field commutator does not vanish on the space-like surface. As the Symposium has shown, the overcoming of divergences on the basis of the indefinite metric leads to the same causality violation. One attempts to make the main difficulty of nonlocal theory in question less serious by such a mean of causality violation which would concern only micro-regions. The conditions of "micricausality" violation have been widely discussed at the Symposium. Unfortunately the idea of causality violation in small regions has not found yet its clear physical interpretation.

It would be desirable to know the physical content of such assertions, the price which should be paid for the refusal from causality in small. It would be desirable to imagine, to predict those physical observable phenomena which would be a consequence of such a violation. Besides, frankly speaking it is not clear how consistently one may admit microcausality violation without breaking macrocausality, to what extent this concerns the accuracy of the experiment and how look these unlikely rare violations of macroscopic causality. It seems that one may be satisfied with a solution of the problem when the causality violation would not be allowed in small too, but simply at certain distances the idea of causal relation would lose its meaning.

[x/] Gauge noninvariance of the Mie non-linear electrodynamics has been overcome in the Born-Infeld nonlinear electrodynamics. Some forms of nonlinear electrodynamics lead also to signals propagated with a velocity higher than the velocity of light.

Such a situation may arise, e.g., at intervals where the notion of distance ($ds^2 = g_{\mu\nu} dx^\mu dx^\nu$) loses its meaning due to quantum fluctuations of the metric tensor $g_{\mu\nu}$ x/. In other words, the clarification of a possible physical meaning of the causality violation in small should be included in the program of forthcoming symposia.

At this Symposium we have learned some essential things about the specific of nonlocal fields in the aspect of axiomatic approaches. In this aspect nonlocal fields have entered into the general classification of fields. Essential theorems, like the theorem on the unique nature of the local commutation, CPT theorem, have appeared. Various deflections from the traditional local theory have been classified. Further it would be desirable to formulate more clearly the properties of a possible class of the theory in the case of CPT-violation. Experiments on the test of the CPT theorem are being performed, in particular, on the Serpukhov accelerator. Therefore more detailed analysis of the class of theories allowing CPT violation is of not a quite abstract interest.

Much attention has been paid at the Symposium to the mathematical formalism of the field theory. It implies the functional integration methods, geometrization of the field theory formalism, application of algebras of various kinds etc. It should be stressed that new mathematical methods are not yet, so to say, a large productive force. A strong mathematization of the Symposium programme is a new feature in the evolution of the symposia on theoretical physics.

In connection with a certain impoverishment of purely theoretical ideas stimulating the physical experiment, a question may arise whether this is twilight of the theoretical physics or a natural stage in its development. Obviously, the field theory is enduring a peculiar period of its development, when searches for other more perfect formalism are inevitable. It is justified, at least, by the fact that even

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x/ Such a situation may be expected at lengths of the order

$$\ell \approx \sqrt{\frac{\hbar \kappa}{c^3}} \approx 10^{-32} \text{ cm.}$$

in electrodynamics, the theory most greatly developed in mathematical respect, we are not quite certain that the faith in perturbation theory in the discussion of problems of principle associated with divergences may not be shaken in the framework of the more perfect formalism. We may remind that the transition from classical physics to quantum electrodynamics was marked by the decrease of the divergency for the electron proper energy from the linear to the logarithmic one. A hope remained that going beyond the framework of perturbation theory, improving the logarithmic result of the second approximation, the nature might make further "concessions"... A certain preliminary analysis of the situation presented at the Symposium is not, as yet, optimistic in this sense.

We continue to accept with a customary thoughtlessness "the fate gift" in the form of the possibility of renormalization procedure for some modes of interactions. We do not know why an unprecedentedly high-handed treatment of the theory apparatus continues to work[x] i.e. up to day does not contradict experiment. Distortions introduced by this procedure seem to be small and the accuracy of the experiment is still insufficient so that to come into a conflict with this procedure. From this point of view we are much more worried about the cases of unrenormalizable interactions. Various attempts of constructing an effective formalism of unrenormalizable theories have just been considered at this Symposium. In particular, an effective possibility of working with the so-called superpropagators has been discussed.

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[x] In the Preface to the Russian version of his book "Principles of Quantum Mechanics" (Forth edition) P.A.M. Dirac writes that he has not included in the book modern methods of renormalization for the reason that it is impossible to ground them with the same degree of rigor as the remaining ones, and therefore it is doubtful whether they will be kept.

Investigations on the Yang-Mills fields have been presented as still formal examples extending our view on possible properties of fields. Attention should be drawn to an unexpected assertion about the absence of the analogy between Yang-Mills and vector-meson fields in passing into them to electrodynamics when the vector meson mass tends to zero. It is quite possible up to now that in the case of the massive Yang-Mills field this transition should be performed more accurately.

As to the nearest future of the field theory, the forecast seems to be not too optimistic. This remark concerns especially the traditional idea of introducing the field source dimensions by means of various kinds of relativistically invariant form factors. It seems to me that here there is no sufficient clearness in our common aspirations. What do we want to reach in our attempts? What ideal are we striving for? Let us assume that we have succeeded in constructing in the framework of electrodynamics a divergency-free theory, introducing some surprising form factor. The question arises as to how this theory would relate to the real electron. Electrodynamics for the electron self-energy yields a logarithmic divergency: $\Delta m \approx \frac{3\alpha}{2\pi} m_e \ln \frac{M_1}{m_e}$.
All the electron mass is of electromagnetic nature, if

$$\frac{3\alpha}{2\pi} \ln \frac{M_1}{m_e} = 1,$$

or, if the corresponding divergent expressions are cut off at the length

$$r_0 = \frac{h}{m_e c} e^{-\frac{2\pi}{3}\frac{\hbar c}{e^2}} < 10^{-100} \text{ cm} .$$

This length is by many orders of magnitude smaller than the electron gravitational radius $r_g \approx \frac{2 m_e \kappa}{c^2} \approx 10^{-55}$ cm . But, obviously, extremely small length which we have right to consider in modern theory should be smaller than the lengths

$$\ell_g \approx \sqrt{\frac{h\kappa}{c^3}} \approx 10^{-33} \text{ cm} ,$$

at which the quantum fluctuatuations of the metric depriving the notion of distance between two space point of the physical meaning become essential. But at lengths larger than ℓ_g the contribution of the electromagnetic field to the electron mass is small compared with its experimental value[x]. If the situation presented bears some relation to the real electron this would mean most likely that the mass and, in general, the electron nature is of nonelectromagnetic nature and the electron theory which is restricted to the electrodynamics is not, strictly speaking, the theory of this particle. Unfortunately the experimental possibilities of the test of the applicability of quantum electrodynamics, as it follows from the report presented at the Symposium, do not make us happy with their perspectives. However it should be noted that the experiment has covered the hadron lengths[xx]($\frac{h}{m_n c} \approx 10^{-14}$cm) and now the experiment is being performed at lengths $5\text{–}3 \cdot 10^{-15}$cm.

But further progress to smaller lengths encounters difficulties. As it follows from the reports at the Symposium at smaller lenghts the electrodynamic corrections are of the same order of magnitude as those from strong and then, possibly, from weak interactions. It seems that possibilities of further progress to smaller lengths in a purely electromagnetic experiment are restricted perhaps to not more than one order. Of course, the most "pure" results should be expected in (e,e), $(e,\tilde{\tilde{e}})$ and (e,μ) interactions. Undoubtedly, the so-called "weak length" of weak interactions $\ell_W \approx \sqrt{\frac{G_W}{\hbar c}} \approx 10^{-17}$cm is the parameter in the problems in question which is expected to give great hopes. Many phenomena in the weak interaction physics may be expected to be clarified greatly by means of further experiments at these lengths.

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[x] If, as was reported at the Symposium, the account of the highest approximations gives a linear divergency, instead of the logarithmic one, but a very small numerical factor $e^{-1/\alpha}$ in this expression leads all the same to a small contribution of the electromagnetic field to the electron mass.

[xx] This fact is a serious in the theories of strong interactions in which the appropriate form factors are introduced.

Returning to the idea of the construction of electrodynamics free of difficulties connected with divergencies on the basis of the nonlocal concepts it should be stressed that this idea appears to become less and less attractive since we have seen that there are arguments in favor of the fact that the electron nature may be of nonelectromagnetic origin. The idea of the form factor eliminating divergences would be of a certain interest if only one given field defined mainly the particle properties and the other fields gave improvements, corrections, or any, more general, "proto-field", proto-matter, defined the spectrum of existing particles.

It should be said that the tendencies in physics are of a rather opposite charcater. Obviously, as concerns the strongly interacting particles, the situation favours the recognition of the so-called nuclear democracy. It appears that it is impossible to single out among strongly interacting fields (particles) some predominant, fundamental field. There are certain grounds to suggest that the so-called weak interactions may enter at small distances into the rank of the strong ones, as well. Long ago we have already got accustomed to the idea that the properties of a given elementary particle are, strictly speaking, defined by the properties of all the remaining particles available in the nature. If in the future the investigations at small lengths (small collision parameters) will lead really to a universal democracy of particles, then our attemts in constructing a closed theory in the framework of one given field should be reasonably estimated. In conclusion I would like to say some words about a possible role of the gravitational fields in the elementary particle theory. It seems to me that there existed and is being existed a preconceived scientific opinion that gravitation must not be of essential importance in the theory of elementary particles. Obviously, the weakness of these forces at nuclear distances might be an argument in favor of such an opinion, provided that these distances define the nature of fundamental particles. It is surprising that this psychologic barrier was also acting for half a century in theory, e.g. in electrodynamics in the apparatus of which integrations over an arbitrary small volume arise, arbitrary large divergent values of the particle masses take place, emission and absorption of quanta of arbitrary high energy are discussed.

It would seem that in these cases there arise, in principle, infinitely large gravitational forces, but in calculations they are completely disregarded. The arising gravitational fields are such that the electromagnetic interactions taken into account are negligibly weaker than disregarded gravitational forces. It is surprising that with such a thoughtless calculation of the divergent integrals we take the liberty of asserting that electrodynamics leads to the divergent value of the electron proper mass. Of course, we may neglect the fact that gravitational forces may play the role of a field regularizator.

But the prejudices of the scientific public opinion are such that a correct analysis of the situation is still absent. It is interesting to note that the most strict mentors of the scientific public opinion like Landau[4] and Pauli[5], at the end of their scientific activity, have declared in favor of a possible essential role of gravitation in the elementary particle theory.

The classical consideration of the problem is, to my mind, promising. In the framework of the general relativity a model of the extended particle is possible which is compatible with the requirements of relativistic invariance and, what is the main, of relativistic causality (friedmons). It is essential that, due to the charge of the metric, the propagation of the light signal near such an object is enhanced and, contrary to the traditional nonlocal schemes, its velocity remains always smaller than the velocity of light.

The gravitational mass defect of a dense matter localized in a small region saves the classical theory from divergences. Unfortunately, an appropriate quantum theory has not been constructed yet. But it is doubtful whether it is possible to expect that the gravitational mass defect refuses for some or another reason to work in the quantum domain.

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"Заключительное слово" на Международном совещании по нелокальной теории поля в Азау, март 1970 года

В "заключительном слове" подводятся итоги Международного совещания по нелокальной теории поля в Азау, март 1970 года.

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Conclusion (Summary talk on the reports submitted to the II International Symposium on Non-Local Quantum Field Theory, Azau, March 14-25, 1970)

The results of the II International Symposium on Non-Local Quantum Field Theory are reviewed in this paper.

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