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HIGH ENERGY PHYSICS AND THE FUNDAMENTAL PRINCIPLES OF MODERN THEORY

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HIGH-energy physics began with the study of cosmic rays, but its present flourishing period started much later - during the post-war years, when methods were devised for accelerating particles to relativistic velocities and accelerators were built. The construction of huge accelerators and the development of new experimental methods indirectly influenced and continue to fruitfully influence the development of technology, stimulating it to a new and increasingly high degree of perfection. However, the principal result achieved by experimental and theoretical physicists working in the high-energy field has been the acquisition of new knowledge. The development of this knowledge has had the aspect of a chain reaction with a high multiplication factor.

A few years ago all elementary particles could easily be listed on a single page, whereas the list now fills four solid pages. The term "elementary particle" can now be regarded as correct only in a traditional sense. The study of electron and pion scattering by nucleons has shown that nucleons have a spatial structure. The discovery of excited states of nucleons (isobars) confirms the complexity of nucleons. A few years ago many physicists were inclined to consider elementary particles as "points," but this primitive conception must now be entirely rejected. In addition to isobars an entire family of hyperons has been discovered, and these can be regarded as nucleonic states excited by K mesons.

The realm of mesons has expanded. Moreover, we can now speak of mesonic matter consisting of short-lived particles - the resonances. The realm of the light particles - leptons - has been enlarged by the addition of a second neutrino. Antiparticles have been discovered, thus creating a real basis for the study of antimatter. Physicists now not only have a large number of new particles, most of which are very complicated, but also an enormous accumulation of facts regarding the laws of their creation, interactions, and decay.

The key to understanding the laws of this new world has thus far been found in the theory of relativity and in quantum field theory. So far not a single fact in the physics of high energies and elementary particles has conflicted with the principles of relativity.

The basic principles of quantum field theory (local fields, quantization rules, symmetry laws etc.) also do not lead to any direct conflict with experimental facts. In addition, in some special directions important successes have been achieved in understanding new physical laws. One of these successes of contemporary theory is the systematization of elementary particles to form multiplets and the calculation of mass splitting in these multiplets leading to a prediction of the existence and mass of the Ω^- hyperon.

Nevertheless, the situation in high-energy physics is very similar to that which existed in the quantum theory of the atom before the discovery of quantum mechanics. We know that some atomic phenomena were successfully predicted, both qualitatively and quantitatively by the old quantum mechanics. We cannot help noticing, particularly, the analogy between the old theory of atomic level splitting in a magnetic field (the Zeeman effect) and the contemporary theory of the multiplet splitting of elementary particles under the influence of a vacuum field that destroys unitary symmetry.

Despite the partial success of the old quantum mechanics, the essential nature of atomic mechanics remained unclear until the appearance ot wave mechanics, when a new fundamental idea, wave motion, was incorporated into atomic theory. It is now entirely clear that Newtonian mechanics, even when supplemented by Bohr's quantum rules, was too crude an instrument to probe the interior of atoms.

We are now also using ideas and concepts that may not justifiably be applied to the new region of investigation. For example, we use the concept of a field $\psi(x)$ inside an elementary particle, although it is clear that the concept of the x coordinate can be given no meaning different from the x coordinate of a point particle.[1]

We are employing the macroscopic principle of causality down to the very smallest order of magnitude, although it can be shown that the uncertainty principle does not permit us to convict a particle of violating causality.[2] It is extremely doubtful that the conventional ideas of space and time can be applied to the interior of a particle.[3,4] We believe in the homogeneity and isotropy of space, although the experimental basis for this conviction leaves much to be desired.[5] An experimental proof that the basic principles of modern theory are inapplicable would have revolutionary significance for the development of elementary particle theory.

The possible violations of these principles could be of two types: (a) They might pertain to the structure of free space-time; (b) they might occur only inside elementary particles or while they are in close interaction. Violations of type (a) could be discovered by studying the homogeneity and isotropy of space-time for sufficiently small dimensions of a.[5] The following tests are possible:

1) A test of invariance by comparing phenomena in the laboratory system of coordinates (in conventional accelerators) with similar phenomena occurring in the center-of-mass system (in accelerators with colliding beams).

2) A test of the conversion from the laboratory system to the c.m. system by comparing the decays of resonances moving with different velocities.

3) A test of the laws of energy and momentum conservation, which could be violated in inhomogeneous space-time.

Violations of type (b) appear to be of a more subtle nature. For their discovery we can thus far only suggest certain relations between the analytic properties of amplitudes A and causality.[6,7]

The following tests are possible:

1) A check of the dispersion relations for π-N scattering. We here have in mind a comparison of Re A for forward scattering with the dispersion integral.[8-11] The study of π-N scattering is to be preferred because the dispersion integral has no unphysical region.

2) A test of the asymptotic relations for cross sections at high energies, such as the relations for the total scattering cross sections of $\pi^{\pm}$ mesons by nucleons: $\sigma_{\pi^+N} = \sigma_{\pi^-N}$ for $E \rightarrow \infty$, where E is the pion energy.[12,13]

In [14-16] several similar new relations were established for other processes, for both total and differential cross sections. All these relations are based on the definite analytic behavior of the scattering amplitude, having as a necessary condition the observance of conventional microcausality.[12]

At the present stage reached in the development of both theory and experiment it is impossible to state the magnitude of the "elementary" length a that could serve as a scale for measuring the region of space-time within which the principles of contemporary theory are violated. All data indicate a magnitude $< 10^{-14}$ cm for this length. Consequently, the c.m. energy of particles should be greater than 1 GeV, with $E_0 \gg 1$ GeV in the laboratory system. Therefore the energy region 10 GeV $< E_0 <$ 100 GeV seems to be a minimum requirement. Hence it seems advisable to construct accelerators reaching 100 GeV and higher, as well as colliding-beam accelerators.

The creation of a new theory is not only a gigantic leap forward in the development of the scientific view of the world, but the history of science shows that it has always had revolutionary influence on the development of the applied sciences and therefore on the entire life of human society.

Illustrations of the foregoing thesis taken from the recent past are the discoveries of relativity theory and of quantum mechanics, without which it is unthinkable that we could have made the progress that has led to the conquest of atomic energy and to coherent light beams, two of the very greatest achievements of modern applied science.

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[1] D. I. Blokhintsev, Problems of the Structure of Elementary Particles, in Filosofskie problemy fiziki elementarnykh chastits (Philosophical Problems of Elementary Particle Physics), AN SSSR, Moscow, 1963, p. 47.

[2] D. I. Blokhintsev, Preprint R-1091, Joint Inst. Nucl. Res., Dubna, 1962.

[3] Blokhintsev, Gol'fand, Kadyshevskiĭ, Kirzhnits, and Kolerov, in Prostranstvo, vremya, prichinnost' v mikromire (Space, Time, and Causality in the Microcosm), Joint. Inst. Nucl. Res. D-1735, Dubna, 1964.

[4] G. Chew, Address at the theoretical discussion at CERN, 1962, UFN **84**, 737 (1965).

[5] D. I. Blokhintsev, Phys. Letters 12, 272 (1964).

[6] M. L. Goldberger, Phys. Rev. **99**, 979 (1955).

[7] Bogolyubov, Medvedev, and Polivanov, Voprosy teorii dispersionnykh sootnosheniĭ (Problems in the Theory of Dispersion Relations), Fizmatgiz, Moscow, 1958.

[8] D. I. Blokhintsev and G. Kolerov, Nuovo cimento 34, 163 (1964).

[9] V. S. Barashenkov and V. I. Delyu, Preprint R-1598, Joint Inst. Nucl. Res., Dubna, 1964.

[10] N. Khuri and T. Kinoshita, in The Nature of Matter, Brookhaven, 1965 (Russ. Transl. on p. 641 of this issue of UFN).

[11] Blokhintsev, Bogolyubov, Markov, and Pomeranchuk, Trudy Mezhdunarodnoĭ konferentsii po uskoritelyam (Trans. Intern. Conf. on Accelerators), Dubna, 1963, Atomizdat, Moscow, 1964.

[12] I. Ya. Pomeranchuk, JETP 34, 725 (1958), Soviet Phys. JETP 7, 499 (1958).

[13] N. N. Meĭman, Voprosy fiziki elementarnykh chastits (Problems in Elementary Particle Physics), Acad. Sci. Armenian SSR, Erevan, 1962, p. 222.

[14] L. Van Hove, Phys. Letters 5, 252 (1963).

[15] Logunov, Van Hieu, Todorov, and Khrustalev, Phys. Letters 7, 69 (1963); JETP 46, 1079 (1964), Soviet Phys. JETP 19, 732 (1964).

[16] Logunov, Van Hieu, and Hsien, Nuovo Cimento **33**, 1312 (1964).

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