SOVIET PHYSICS USPEKHI VOLUME 10, NUMBER 3 NOVEMBER-DECEMBER 1967

53

Personalia

ISAAK YAKOVLEVICH POMERANCHUK

V. B. BERESTETSKIĬ

Usp. Fiz. Nauk 92, 355–365 (June, 1967)

SOVIET and world scientists suffered a heavy loss on 14 December 1966 when the outstanding Soviet theoretical physicist, Academician Isaac Yakovlevich Pomeranchuk, died at 54 after a heavy illness.

Pomeranchuk's contribution to the development of physics is very large. He discovered, i.e., theoretically predicted, many interesting phenomena which, some immediately and others after a number of years, depending on the degree to which the experimenters and their instruments were ready, were observed experimentally and served as a basis for further research. Such "Pomeranchuk effects" are found in solid-state physics, in low-temperature physics, in electrodynamics of electrons, positrons, and mesons, and in other branches of physics.

When nuclear physics became a separate branch and acquired tremendous practical significance, Pomeranchuk's work served as a basis for the development of the theory of neutron reactors in our country. When elementary-particle physics came into being and started to develop rapidly, Pomeranchuk devoted himself completely to its difficult problem. It was there that he initiated a new trend in science - the physics of extremely high energies.

Pomeranchuk's work, both recent and earlier, his problems, his effects, his remarkable "theorem," are alive now and will remain alive long not only in the history of science but in the daily work of physicists, both theoretical and experimental.

Pomeranchuk's importance to science is far from limited to these results. Pomeranchuk belonged to that rare and valuable group of scientists, without which science could not rise or, as stated by Einstein, could not make a forest out of isolated trees. For people of Pomeranchuk's type science is an direct all-absorbing organic necessity. The value of such persons was tremendous at all times, and becomes even more considerable in our day, when science has attracted a large number of people, and when science has broadened so much. Pomeranchuk was that pure tone, which by its sound alone rendered inestimable service to all physicists, both young and mature. Pure tone is not produced by pulses. Pomeranchuk's whole life produced such a tone.

Pomeranchuk was born on 20 May 1913 in Warsaw. His father, Yakov Isaakovich, was a chemical engineer, his mother, Amaliya Davydovna, was a physician. During the time of the first world war the family moved to Rostov, and then to Rubezhnyĭ in Donbass,

where Pomeranchuk finished the 7-year school in 1927 and the 12-year FZU school of the Rubezhnyĭ Chemical Plant in 1929. After serving as a worker in this plant for two years, he entered in 1931 as a first-year student of the Ivanovo Chemical-technological Institute. In the second year he transferred to the Physico-chemical Department of the Leningrad Polytechnic Institute, from which he was graduated in 1936.

His scientific activity began in 1935 at the Physico-technical Institute in Khar'kov, under the leadership of L. D. Landau. He reported to Landau in Khar'kov as a student finally resolved to engage in theoretical physics. The dean's standard answer to young people wishing to specialize in theory was that "Einstein worked in the patent bureau, and Dirac finished a technical school," followed by a refusal. Pomeranchuk reacted simply - he went to Khar'kov without permission. In two months he passed the examination for the minimum theoretical requirements, just introduced by Landau. Landau exerted a deep influence on the development of Pomeranchuk as a scientist, and the friendship with Landau lasted all his life. When already a mature theoretician, always rich with new ideas, Pomeranchuk loved most of all to "try them out on the teacher."

His first investigation, carried out together with A. I. Akhiezer and L. D. Landau and published in August 1936 in "Nature," was devoted to the question of scattering of light in the case when the energy of the colliding photons is much larger than the electron mass. In the same 1936, Landau and Pomeranchuk published a paper in which they considered for the first time effects connected with the interaction between the conduction electrons of a metal; prior to this paper, the aggregate of conduction electrons was always regarded in the electron theory of metals as a gas whose particles interact only with lattice vibrations. The main result of this paper was that the influence of the electron interaction on the electric resistance leads to a T^2 dependence of the resistance of the pure metal at low temperatures.

Out of the whole manifold of Pomeranchuk's research on solid-state physics, it is necessary to separate two groups of papers, which have gained him world fame and acknowledgement. We refer to work connected with neutron scattering in crystals and to the theory of thermal conductivity of dielectrics.

In the work on the theory of scattering of slow neutrons in a crystal (1938), and in a later investigation carried out jointly with A. I. Akhiezer (1947), he presented a general theory of inelastic neutron scattering accompanied by single-phonon and many-phonon excitations in the crystal. These papers served in fact as the starting point for a whole number of later investigations which led, in particular, to the creation of the method of reconstructing the phonon spectrum of crystals on the basis of measuring the doubly-differential scattering cross section of slow neutrons. The same cycle of investigations includes work on neutron refraction (1948), where a whole number of relations very close to the optical ones was derived for slow particles.

It should be specially noted that one chapter in a book "Certain Problems in Nuclear Theory" (written by Pomeranchuk with A. I. Akhiezer more than 15 years ago) is devoted to the interaction between slow neutrons and matter, and is still the best available introduction to this problem.

Anharmonic interactions of phonons in crystals and the general problem of lattice thermal conductivity always were and still remain one of the most interesting problems in solid-state physics. Pomeranchuk made the first major step in the development of this field. In his doctoral dissertation, defended in 1940, he presented a detailed analysis of three-phonon and four-phonon interactions in a crystal; he constructed a theory of the thermal conductivity of dielectrics at both low and high temperatures.

Pomeranchuk called attention to the principal faults of earlier theories of thermal conductivity of dielectrics. He showed that cubic anharmonicity of the oscillations of atoms in the crystal lattice, in spite of the prevailing opinion, is actually as a rule insufficient for establishment of the final thermal conductivity; to obtain the final result it is necessary to take into account anharmonicity of higher orders. The joint action of these anharmonicities and of other sources of phonon scattering (impurities, reflection from the walls of crystallites, scattering by elastic deformations) leads to a complicated picture, which was investigated by Pomeranchuk in exhaustive detail. The laws that should govern the variation of the thermal conductivity of dielectrics as a function of the temperature, impurity concentration, and crystallite dimensions in different ranges of values of these parameters and for different types of crystal structures were determined. This cycle of investigations is very characteristic of Pomeranchuk's entire creativity, for here physical intuition played no less important a role than the formal apparatus. In this connection it is instructive, that although the entire problem as a whole has subsequently been extensively developed, the problem raised by him, that of the special role of long-wave phonons in the thermal conductivity of crystals, which is frequently called the "Pomeranchuk problem," still remains timely today.

From among other work by Pomeranchuk on solid-state physics, special note should be taken of work devoted to the isotopic effect in the residual resistance of metals (1958). There he called attention for the first time to the fact that although the amplitudes for the scattering of electrons by ions of different isotopes in a metal have the same value, violation of rigorous periodicity in the dynamic picture of the oscillations (as a result of the different masses of the isotopes) leads to a finite resistance in metals even at $T = 0$. This is a far from trivial effect, and there is no doubt that it will be observed experimentally in the nearest future.

Related to Pomeranchuk's research on the solid state are his investigations on the theory of the quantum liquid He II and He^3. In work on the motion of extraneous particles in He II, published together with L. D. Landau in 1948, it is shown on the basis of simple qualitative considerations that any particle dissolved in superfluid helium should take part in the normal (and not superfluid) motion, i.e., it should enter into the normal component of the liquid regardless of the statistics that the particles obey in themselves. This paper was of fundamental significance; it brought to an end the hitherto existing incorrect notion that the part that impurities play in the superfluid motion depends on the statistics. It followed from this paper, in particular, that the normal part should include small impurities of both the isotope He^3 (which obeys Fermi statistics) and the isotope He^6 (which obeys Bose statistics), as was indeed confirmed by subsequent experiments.

The influence of impurities on the thermodynamic and hydrodynamic properties of liquid helium were subsequently investigated in detail by Pomeranchuk in 1949.

In a paper devoted to the theory of liquid He^3 (1950) he presents, for the first time, a qualitative analysis of quantum liquids with a Fermi energy spectrum. He shows that the viscosity of such a liquid should increase with decreasing temperature like $1/T^2$. He also shows that in liquid He^3 an important role is played by exchange effects, which lead to unique phenomena when liquid He^3 solidifies. The presence of magnetic ordering of the nuclear spins in the liquid and the absence of this ordering in the solid crystal causes the entropy of the solid phase to become larger (at sufficiently low temperatures) than in the liquid phase - a situation which is the opposite of the usual one. As a result, the existence of a minimum on the phase equilibrium (the pT diagram) of helium was predicted - the famous Pomeranchuk effect, which was fully confirmed by subsequent experiments. Most recently, this singularity of liquid He^3 has been successfully used to obtain infralow temperatures.

Pomeranchuk made a very important contribution to the construction of nuclear reactors in the Soviet Union. He started to work on this problem in 1943. This year heralds the development in our country of a broad front of scientific research devoted to the mastery of atomic energy. As is well known, this problem was brilliantly solved in record short time.

Pomeranchuk immediately became one of the closest assistants of the scientific director of the entire problem, I. V. Kurchatov, and headed the development of the theory of atomic reactors. With the exception of the work by Ya. B. Zel'dovich and Yu. B. Khariton, which was performed before the War, reactor theory started to become intensely developed just in 1943, and primarily owing to the work of Pomeranchuk.

In solving the problem of realizing a non-attenuating chain nuclear reaction (creation of the first Soviet physical reactor), a basic role was played by the so-called exponential experiments performed by I. V. Kurchatov. These experiments made it possible to determine such important quantities as the absorption of thermal neutrons by the moderator, and the fission-neutron moderation length. These experiments would have been impossible without the theory of the exponential experiments, and this theory was constructed by Pomeranchuk who thus ensured the realization of the most important stage in the mastery of nuclear energy in our country.

An even more fundamental contribution made by Pomeranchuk to the theory of reactors was the theory of resonant neutron absorption in heterogeneous systems, which he developed. As is now well known, only heterogeneous arrangement of uranium blocks in the moderator makes it possible to effectively realize an undamped chain reaction in systems of natural uranium and a moderator. The theory of resonant absorption in block systems, which Pomeranchuk developed in conjunction with I. I. Gurevich, yields, in spite of its seeming simplicity, a deep physical insight into the phenomenon. Pomeranchuk's model of resonant absorption by blocks, as shown by experimental investigations carried out much later, turned out to be much more equivalent to the real picture than the Wigner model which was independently developed in the USA.

Most valuable is Pomeranchuk's work on the theory of critical dimensions. Thus, Pomeranchuk derived a formula for the critical dimension in the age approximation. Important work was done by him on the theory of temperature effects in reactors. Pomeranchuk was the first to investigate neutron multiplication during moderation.

Being one of the creators of diffusion theory of reactors, Pomeranchuk was the first to create the foundations for a more exact theory, starting to employ systematically kinetic equations for the processes of moderation and diffusion of neutrons in a reactor.

Pomeranchuk's contribution to the theory of nuclear reactors is not limited to his own direct participation and his scientific papers. His brilliant creative manner, combining clear physical thinking with mastery of all mathematical difficulties, affected most deeply the work of his students and successors. One can state without exaggeration that the Soviet school of nuclear reactors is to a considerable degree Pomeranchuk's creation.

Several of Pomeranchuk's investigations were devoted to the theory of magnetic bremsstrahlung (synchrotron) radiation, which is produced when a relativistic charged particle moves in a magnetic field. The first paper in this field was published in 1939. Attention was called in it to a characteristic feature of electrons radiating while moving in a magnetic field: The intensity of the radiation increases with energy, so that after the particle moves in a magnetic field for a specified time interval, the particle energy, regardless of its initial value, tends to a certain limit. For this reason, for example, an electron incoming from outer space moving in the earth's magnetic field should lose energy in such a way that its energy on the earth's surface cannot exceed 5×10^{17} eV. In subsequent investigations (1945, 1946), attention was called to the important role of synchrotron-radiation losses of energy when electrons move in cyclic accelerators (betatron and synchrotron), and a more detailed analysis of the radiation was performed. Pomeranchuk did not return to this problem subsequently, but it continued to exist independently. This singularity in the behavior of charged particles in a magnetic field, discovered by Pomeranchuk, turned out to hold also when an electromagnetic wave of sufficiently low frequency moves in a field. This effect (the existence of a limiting energy) is very important in the analysis of the origin of cosmic rays.

For many years Pomeranchuk engaged in an investigation of the interaction between radiation and matter. He performed a theoretical analysis of the question of fluctuations of ionization ranges of charged particles in matter. The solution of this problem turned out to be very important for experiments with cosmic rays. Investigating the radiation of quanta by heavy particles, Pomeranchuk (together with I. M. Shmushkevich) has shown that the presence of exchange forces between the proton and the neutron should lead to an appreciable increase in the intensity of photon emission when collisions take place between these particles or when these particles collide with nuclei.

Very important work was done by Pomeranchuk in conjunction with L. D. Landau on electron-cascade processes at high energies. It was shown in their papers that because the distances on which electron bremsstrahlung occurs increase with increasing electron energy, a whole aggregate of atoms of the medium take part in the bremsstrahlung process simultaneously if the energies are sufficiently high. The action of a large number of atoms causes multiple Coulomb scattering of the electrons during the time of the bremsstrahlung act, and causes the Bethe-Heitler formulas to be inapplicable at high energies. Landau and Pomeranchuk obtained qualitative estimates of the influence of multiple scattering on bremsstrahlung and pair production. Subsequently this problem has turned into an entire field of physics, which has received wide development.

In 1947 Pomeranchuk calculated the cross sections for the annihilation of positrons by electrons with allowance for polarization, and observed that two-quantum annihilation is forbidden in the ^3S state with total spin 1. This paper was the basis of further development of positronium theory. At the present time the physics of positronium and its applications constitute an independent discipline. The effect observed by Pomeranchuk has made positronium a subtle indicator used in various investigations.

In 1952 Pomeranchuk, together with A. D. Galanin, considered the influence of vacuum polarization on the level splitting of μ-mesic atoms. Unlike the ordinary atoms, where the contribution of the polarization of vacuum is small, in μ-atoms, owing to their small radius, the muon is in a region where the vacuum polarization makes a large contribution. The phenomenon observed in this paper is of interest from both the theoretical point of view (the possibility of observing polarization of vacuum) and from the point of view of the physics of mesic atoms. Experiments have confirmed this idea.

The early 50's - the time when mesons were beginning to be artificially produced in the laboratories - was the time when physics of elementary particles in the modern sense of this word was created. Since that time, Pomeranchuk's interests were concentrated more and more on the problem of strong interactions of elementary particles. During the first stage he developed a phenomenological approach to the theory of strong interactions. In a cycle of his papers with various co-authors he developed the theory of interaction of pions with deuterons. This theory (the so-called impulse approximation) relates the cross section of processes occurring when mesons collide with deuterons, on the one hand, with the cross sections of processes occurring when the mesons collide with free nucleons. Pomeranchuk's analysis of deuteron reactions is of great importance. Most information on the interactions with neutrons at high energies are obtained by physicists through experiments with deuterons. Subsequently (1958) the impulse approximation received a different formulation on the basis of pole diagrams.

In 1953, after it became finally clear that pions interact strongly with nucleons and that perturbation theory is not at all applicable to pion-nucleon interactions, Pomeranchuk turned to the following fundamental problem: investigation of general properties of the equations of quantum field theory in those cases when the interaction cannot be regarded as small. At that time Landau and his co-workers obtained a solution of the equations of quantum electrodynamics at high energies. Pomeranchuk analyzed this solution and showed, jointly with L. D. Landau, that its properties lead to the possibility of neglecting, in the Lagrangian of the system of electrons and quanta at high energies, the action of the free electromagnetic field in that region where the effective charge is still small. This led to the very important conclusion that in quantum electrodynamics any arbitrarily large Baier charge is fully screened by charges produced as a result of polarization of vacuum, so that the physical charge of the electrons observed at large distances should be equal to zero. This indicated by the same token an internal contradiction in quantum electrodynamics. For electrodynamics, problems connected with zero charge may turn out to be significant only at energies $\sim m_e e^{137}$, and do not concern the region where ordinary renormalization technique, developed by Schwinger and Dyson, is sufficient for the solution of real problems. This may not be the case for mesonic theories with strong coupling. Developing these ideas, Pomeranchuk has shown that in meson theory there should occur a similar situation, with vanishing of the physical charge, i.e., there are serious grounds for assuming meson theory to be likewise internally contradictory.

The conclusion of the internal contradiction of the theories using the Lagrangian method has led Pomeranchuk to search for other approaches to the theory of strong interactions, without using field-theory equations. Pomeranchuk returned to a phenomenological approach. On the basis of the general properties of the amplitudes of quantum field theory, he showed that the scattering phases with large orbital angular momenta are determined by pole diagrams corresponding to exchange of the easiest particle. A theoretical calculation of the phases due to exchange of one and two mesons, carried out on the basis of these considerations, has made it possible to simplify greatly the phase shift analysis of nucleon-nucleon scattering.

Over a long time (dating back from 1946), Pomeranchuk has returned many times to the model of diffraction strong interaction at high energies. This model regarded the particle as black spheres and made it possible to predict certain properties of the processes, without specifying concretely the interaction mechanisms. Essentially, it is precisely the diffraction concept which led him in 1956 to formulate the prediction that in the high-energy limit the cross sections of charge-exchange processes should vanish, and the cross sections of elastic processes for particles from a given isotopic multiplet should not depend on their charges. On the other hand, he was the first to call attention to the unsatisfactory nature of the diffraction theory. Investigating the reaction of creation of several particles at small target-recoil momenta, Pomeranchuk, working with V. B. Berestetskiĭ, reached the conclusion that ordinary diffraction theory leads to difficulties and calls for essential modifications.

Pomeranchuk did not turn to the field of extremely high energies by accident. He sought in strong-interaction physics an object in which the most complicated laws of strong interaction would become manifest in simplest fashion. It is known that a decisive role was played in the creation of quantum mechanics by the knowledge of the properties of the simplest quantum-mechanical system, the hydrogen atom. In creating the theory of strong interactions, Pomeranchuk assigned the role of the "hydrogen atom" to interaction processes at asymptotically high energies. In 1958, on the basis of an analysis of the dispersion relations, Pomeranchuk formulated his famous theorem, according to which the cross sections for the interaction of a particle and an antiparticle with a nucleon should be the same at extremely high energies.

Pomeranchuk's theorem heralded the creation of the new field of science - physics of extremely high energies. In subsequent years this science experienced a rapid and fruitful development. It was developed by theoretical physicists in dozens of scientific centers in the entire world. The largest accelerators were used for an experimental verification of its predictions. Pomeranchuk was the acknowledged leader of this trend. Together with V. N. Gribov, starting in the 60's, Pomeranchuk has developed an approach to the theory of asymptotes, based on the mathematical apparatus of complex angular momenta, which was introduced somewhat earlier by T. Regge.

Almost all the essential results obtained in that field are connected with Pomeranchuk's name. In 1962–1964 he actively investigated the properties of diffraction scattering due to one Regge pole, which subsequently was named the Pomeranchuk pole. The results of these investigations were important theorems of the relations between the cross sections of different processes, the properties of the trajectories of the Pomeranchuk pole, the existence of a maximum in backward scattering, the existence of polarization phenomena at high energies, and others. He simultaneously developed also the purely theoretical aspects of the method of complex angular momenta. He established the condensation of the Regge poles at threshold values. He observed the remarkable property of the singularity of the partial wave at an angular momentum equal to −1, which served as the beginning of a new stage in the development of the theory of complex angular momenta, namely the observation of branch points in the plane of complex angular momenta. Pomeranchuk's work played a major role in this stage, too. He investigated the structure of the branch points in the complex plane and predicted the idea that the branchings become intensified by the pole, thus presenting an entirely new formulation of the problem of the structure of the diffraction cone.

Pomeranchuk attached great importance to the method of complex angular momenta. For him this was not only a means of describing processes at high energies, but also a new language in the theory of strong interactions, in which there are no particles as an object of investigation, and their place is occupied by the Regge-pole trajectories.

Pomeranchuk developed a large school of Soviet theoretical physicists. He organized the Theoretical Division of the Institute of Theoretical and Experimental Physics and led it since the foundation of the Institute to the last days of his life. He was the founder and for many years the director of theoretical groups at the Kurchatov Institute of Atomic Energy and at the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research; his influence was usefully felt in the choice of the principal direction of their work. For twenty years he was professor of the Moscow Engineering-Physics Institute.

Pomeranchuk worked much with his students, graduate students, and young theoreticians. Many of the presently active scientists owe their success to his guiding attention.

For his scientific work, Pomeranchuk was twice awarded a state prize of first degree. He was awarded the Order of Lenin, the Order of Labor of Red Banner, and the Order of Merit.

In 1953 he was selected Corresponding Member of the Academy of Sciences of the USSR, and in 1964 he became a full member.

Pomeranchuk was modest and even shy, when it came to his personal convenience; but he was completely transformed, becoming persistent and inflexible when it came to the interests of science.

Pomeranchuk loved physics very much. He was enthusiastically glad with each new scientific result, regardless of to whom it belonged. The love for physics denoted for him persistent work, continuous intense thought on concrete problems accompanied by mathematical derivations. Work was his greatest joy. He was untiring. He lived with physics. He sincerely could not understand how it is possible to waste time on anything else. The guiding principle, for him, was establishment of scientific truth. It was precisely this criterion which determined his relation to physical ideas and projects, scientific articles, and people. He always strived forward. When he was told how one of the "Pomeranchuk effects" began to "work," he only smiled weakly and somewhat guiltily. What of it, if there is so much still inexplicable, so many problems for which there is no approach yet? He personally carried the burden of human thirst for knowledge.

Even the terrible sickness, cancer of the oesophagus, did not change his behavior. Pomeranchuk continued to work intensely, literally to his very last day. He worked while in the hospital and worked at home. He was visited almost daily by theoretical physicists and experimenters. He discussed scientific problems; he was stimulated by everything connected with the development of physics in our country. His last scientific work - on the behavior of the total cross section of annihilation of electron-positron pairs into hadrons at high energies - was completed by Pomeranchuk two days before his death, 12 December 1966.

Pomeranchuk's bright memory will always live in the heart of those who were fortunate to be his students, co-workers, and in the hearts of all those who ever communicated with him.

It is impossible to imitate such a life. But the very existence of such a life will long serve as a real force in the development of science.

LIST OF SCIENTIFIC PAPERS BY ACADEMICIAN I. Ya. POMERANCHUK

Theory of Elementary Particles

[1] A. I. Akhieser, L. Landau, and I. Pomeranchuk, Scattering of Light by Light, Nature **138**, 206 (1936).

[2] I. Pomeranchuk, The scattering of mesotron pairs by positron annihilation, J. Phys. USSR **4**, 277 (1941).

[3] I. Pomeranchuk, The scattering of mesotrons by mesotrons, J. Phys. USSR 4, 277 (1941).

[4] I. Pomeranchuk, Coulomb Forces and Structure of the Neutron, DAN SSSR **41**, 162 (1943).

[5] I. Pomeranchuk, Scattering of Mesons Strongly Interacting with Nucleons. DAN SSSR **44**, 13 (1944).

[6] I. Pomeranchuk, Generalization of Limiting λ Process and Non-uniqueness in the Elimination of the Infinities of Quantum Theory of Elementary Particles, JETP **17**, 667 (1947); Phys. Rev. **76**, 298 (1949).

[7] I. Ya. Pomeranchuk, Selection Rules in the Annihilation of Electrons and Positrons, DAN SSSR **60**, 213 (1948).

[8] A. I. Akhiezer and I. Ya. Pomeranchuk, On the Determination of Non-electromagnetic Interactions between Electrons and Neutrons. JETP **19**, 558 (1949).

[9] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, On β Decay of the Neutron, JETP **19**, 591 (1949).

[10] I. Ya. Pomeranchuk and I. M. Shmushkevich, Radiation in Collisions of Fast Neutrons with Protons, DAN SSSR **64**, 499 (1949).

[11] I. Pomeranchuk and I. Shmushkevich, Electromagnetic Radiation under the Influence of Exchange Forces, DAN SSSR **70**, 33 (1950).

[12] V. B. Berestetskii and I. Ya. Pomeranchuk, Transformation of Charged Pion into a Neutral Meson upon Collision with a Proton and a Deuteron, DAN SSSR **77**, 803 (1951); JETP **21**, 1313 (1951).

[13] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, Collision of Pions with Deuterons, DAN SSSR **81**, 1019 (1951).

[14] I. Ya. Pomeranchuk, Theory of Formation of Many Particles in One Act, DAN SSSR **78**, 889 (1951).

[15] I. Ya. Pomeranchuk, Exchange Collisions of Fast Nucleons with Deuterons, DAN SSSR **78**, 249 (1951).

[16] I. Ya. Pomeranchuk, Exchange Collisions of Fast Nucleons with Deuterons. I. JETP **21**, 1113 (1951).

[17] I. Ya. Pomeranchuk, Capture of π Particles in a Deuteron, DAN SSSR **80**, 47 (1951).

[18] I. Ya. Pomeranchuk, Exchange Collisions of Fast Nucleons with Deuterons. II. JETP **22**, 624 (1952).

[19] I. Ya. Pomeranchuk, Contribution to the Theory of Capture of π Particles in a Deuteron, JETP **22**, 129 (1952).

[20] A. D. Galanin and I. Ya. Pomeranchuk, Spectrum of μ-mesic Hydrogen, DAN SSSR **86**, 251 (1952).

[21] I. Ya. Pomeranchuk and I. M. Shmushkevich, Emission of γ Quanta of High Energies in Collisions of Fast Neutrons with Protons, DAN SSSR **87**, 385 (1952).

[22] L. D. Landau and I. Ya. Pomeranchuk, Emission of γ Quanta in Collisions of Fast Pions with Nucleons, JETP **24**, 505 (1953).

[23] I. Ya. Pomeranchuk and E. L. Feĭnberg, External (Diffraction) Generation of Particles in Nuclear Collisions, DAN SSSR **93**, 439 (1953).

[24] A. D. Galanin, B. L. Ioffe, and I. Ya. Pomeranchuk, Renormalization of Mass and Charge in Covariant Equations of Quantum Field Theory, DAN SSSR 98, 361 (1954).

[25] A. I. Akhiezer and I. Ya. Pomeranchuk, Photon Emission Accompanied by Capture of a Fast Proton by a Nucleus, DAN SSSR 94, 821 (1954).

[26] I. Ya. Pomeranchuk, Semiphenomenological Theory of Production of Pion Pairs by High-energy γ Quanta, DAN SSSR 96, 265 (1954).

[27] I. Ya. Pomeranchuk, Production of Pion Pairs by γ Quanta in the Case of Heavy Nuclei, DAN SSSR 96, 481 (1954).

[28] I. Ya. Pomeranchuk, Vanishing of Renormalized Charge in Quantum Electrodynamics, DAN SSSR 103, 1005 (1955).

[29] I. Ya. Pomeranchuk, Renormalization of Meson Charge in Pseudoscalar Theory with Pseudoscalar Coupling, DAN SSSR 104, 51 (1955).

[30] I. Ya. Pomeranchuk, Vanishing of Renormalized Meson Charge in Pseudoscalar Theory with Pseudoscalar Coupling, DAN SSSR 105, 461 (1955).

[31] L. Landau and I. Pomeranchuk, Point Interaction in Quantum Electrodynamics, DAN SSSR 102, 489 (1955).

[32] I. Ya. Pomeranchuk, Generalization of the Ward Theorem to the Case of Finite Wavelengths of Light and Particles with Zero Spin, DAN SSSR 100, 41 (1955).

[33] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, Production of Pion Pair in Positron Annihilation, JETP 29, 869 (1955), Sov. Phys. JETP 2, 741 (1956).

[34] A. D. Galanin, B. L. Ioffe, and I. Ya. Pomeranchuk, Asymptotic of the Green's Function of the Nucleon and Meson in Pseudoscalar Theory with Weak Interaction, JETP 29, 51 (1955), Sov. Phys. JETP 2, 37 (1956).

[35] I. Ya. Pomeranchuk, Solution of Equations of Pseudoscalar Theory with Pseudoscalar Coupling, JETP 29, 869 (1955), Sov. Phys. JETP 2, 741 (1956).

[36] I. Ya. Pomeranchuk, Isotopic Invariance in Scattering of Antinucleons by Nucleons, JETP 30, 423 (1956), Sov. Phys.-JETP 3, 305 (1956).

[37] B. L. Ioffe, I. Ya. Pomeranchuk, and A. P. Rudik, Dispersion Relations for Scattering of Pions by Deuterons, JETP 31, 712 (1956), Sov. Phys.-JETP 4, 588 (1957).

[38] I. Pomeranchuk, Note on the Number of Different Types of K-mesons, Nucl. Phys. 2, 281 (1956–1957).

[39] B. L. Ioffe, L. Okun and I. Pomeranchuk, Concerning the Number of Different Types of K-mesons, Nucl. Phys. 2, 277 (1956–1957).

[40] L. B. Okun' and I. Ya. Pomeranchuk, Isotopic Invariance and Cross Sections for Interaction of Pions and Nucleons of High Energy with Nucleons, JETP 30, 424 (1956), Sov. Phys. JETP 3, 307 (1956).

[41] I. Pomeranchuk, Vanishing of the Renormalized Charge in Electrodynamics and in Meson Theory. Nuovo Cimento 3, 1186 (1956).

[42] I. Ya. Pomeranchuk, V. V. Sudakov, and K. A. Ter-Martirosyan, Vanishing of Renormalized Charge in Field Theories with Point Interaction, Phys. Rev. 784 (1956).

[43] A. I. Akhiezer and I. Ya. Pomeranchuk, Emission of γ Quanta Accompanied by Absorption of Fast Neutrons by Nuclei, JETP 30, 201 (1956), Sov. Phys.-JETP 3, 127 (1956).

[44] E. L. Feinberg and I. Pomeranchuk, High Energy Inelastic Diffraction Phenomena, Nuovo Cimento 3, Suppl. N4, 652 (1956).

[45] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, Correlation Phenomena in the Capture of K Mesons, JETP 31, 350 (1956), Sov. Phys.-JETP 4, 289 (1957).

[46] B. L. Ioffe and I. Ya. Pomeranchuk, Possible Dipole Moment of the Transition in Λ Particles, DAN SSSR 113, 1251 (1957), Sov. Phys. Dokl. 2, 202 (1958).

[47] I. Ya. Pomeranchuk, Equality of Total Cross Section of Interaction of Nucleons and Antinucleons at High Energies, JETP 34, 725 (1958), Sov. Phys. JETP 7, 499 (1958).

[48] L. B. Okun' and I. Ya. Pomeranchuk, Determination of the Parity of the K Meson, JETP 34, 997 (1958), Sov. Phys. JETP 7, 688 (1958).

[49] L. B. Okun', I. Ya. Pomeranchuk and I. M. Shmushkevich, Interaction of Λ Hyperons with Nucleons and Light Nuclei, JETP 34, 1246 (1958), Sov. Phys.-JETP 7, *62 (1958).

[50] A. I. Akhiezer and I. Ya. Pomeranchuk, Diffraction Phenomena in Collisions of Fast Particles with Nuclei, UFN 55, 593 (1958); Fortschr. Physik 7, 102 (1959).

[51] A. A. Abrikosov, A. D. Galanin, B. L. Ioffe, I. Ya. Pomeranchuk and I. M. Halatnikov, Green's functions in meson theories, Nuovo Cimento 8, 782 (1958).

[52] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, β Interaction and Form Factor of Nucleon, JETP 36, 1321 (1959), Sov. Phys. JETP 9, 936 (1959).

[53] A. D. Galanin, A. F. Grashin, B. L. Ioffe, and I. Ya. Pomeranchuk, Collisions of Nucleons with Large Orbital Angular Momenta, JETP 37, 1663 (1959), Sov. Phys. JETP 10, 1179 (1960); Nucl. Phys. 17, 191 (1960).

[54] L. B. Okun' and I. Ya. Pomeranchuk, Peripheral Interactions of Elementary Particles, JETP 36, 300 (1959), Sov. Phys. JETP 9, 207 (1959); Nucl. Phys. 10, 492 (1959).

[55] V. B. Berestetskiĭ and I. Ya. Pomeranchuk, Asymptotic Dependence of the Cross Sections at High Energies, JETP 39, 1078 (1960), Sov. Phys. JETP 12, 752 (1961).

[56] A. D. Galanin, A. F. Grashin, B. L. Ioffe and I. Ya. Pomeranchuk, Scattering of Nucleon by Nucleon

in Two-meson Approximation at High Orbital Momenta, JETP **38**, 475 (1960), Sov. Phys. JETP **11**, 347 (1960).

[57] V. A. Borovikov, I. M. Gel'fand, A. F. Grashin and I. Ya. Pomeranchuk, Phase Shift Analysis of p-p Scattering at 95 MeV, JETP **40**, 1106 (1961), Sov. Phys.-JETP **13**, 780 (1961).

[58] I. Yu. Kobzarev, L. B. Okun' and I. Ya. Pomeranchuk, Electromagnetic Interaction of Neutral Vector Meson, JETP **41**, 495 (1961), Sov. Phys. JETP **14**, 355 (1962).

[59] Yu. P. Nikitin, I. Ya. Pomeranchuk, and I. M. Shmushkevich, Production of Pion Beams of High Energy, JETP **41**, 963 (1961), Sov. Phys. JETP **14**, 688 (1962).

[60] V. B. Berestetsky and I. Ya. Pomeranchuk, On the Asymptotic Behaviour of Cross Sections at High Energies, Nucl. Phys. **22**, 629 (1961).

[61] I. Ya. Pomeranchuk and I. M. Shmushkevich, On the Process in the Interaction of γ-quanta with Unstable Particles, Nucl. Phys. **23**, 452 (1961).

[62] A. A. Abrikosov, A. D. Galanin, L. P. Gorkov, L. D. Landau, I. Ya. Pomeranchuk and K. A. Ter-Martirosyan, Possibility of Formulation of a Theory of Strongly Interacting Fermions, Phys. Rev. **111**, 321 (1958).

[63] V. N. Gribov, B. L. Ioffe, I. Ya. Pomeranchuk and A. P. Rudik, Certain Consequences of the Moving-pole Hypothesis for Processes at High Energies, JETP **42**, 1419 (1962), Sov. Phys. JETP **15**, 984 (1962).

[64] V. N. Gribov and I. Ya. Pomeranchuk, Complex Orbital Angular Momenta and Relation between Cross Sections of Different Processes at High Energies, JETP **42**, 1141 (1962), Sov. Phys. JETP **15**, 788 (1962); Phys. Rev. Letts. **8**, 343 (1962).

[65] V. N. Gribov and I. Ya. Pomeranchuk, Spin Structure of Meson-nucleon and Nucleon-nucleon Scattering Amplitudes at High Energies, JETP **42**, 1682 (1962), Sov. Phys. JETP **15**, 1168 (1962); Phys. Rev. Letts. **8**, 412 (1962).

[66] V. N. Gribov and I. Ya. Pomeranchuk, Certain Properties of Elastic-scattering Amplitude at High Energies, JETP **43**, 308 (1962), Sov. Phys. JETP **16**, 220 (1963); Nucl. Phys. **38**, 516 (1962).

[67] V. N. Gribov and I. Ya. Pomeranchuk, Limitation of the Rate of Decrease of Amplitudes of Different Processes, JETP **43**, 1556 (1962), Sov. Phys. JETP **16**, 1098 (1963); Proc. Int. Conf. High Energy Phys., Geneva, 1962, pp. 522-524.

[68] V. N. Gribov and I. Ya. Pomeranchuk, Regge Poles and Landau Singularities, JETP **43**, 1970 (1962), Sov. Phys. JETP **16**, 1387 (1963); Phys. Rev. Letts **9**, 238 (1962); Proc. Int. Conf. High Energy Phys., Geneva, 1962.

[69] V. N. Gribov and I. Ya. Pomeranchuk, Asymptotic Behaviour of Annihilation and Elastic Scattering Processes at High Energies, Nucl. Phys. **33**, 516 (1962).

[70] V. Gribov, L. Okun' and I. Pomeranchuk, Processes Determined by Fermion Regge Poles, JETP **45**, 1114 (1963), Sov. Phys. JETP **18**, 769 (1964).

[71] V. N. Gribov, I. Ya. Pomeranchuk and K. A. Ter-Martirosyan, Partial Waves Singularities near j-1 and High Energy Behaviour of the Elastic Scattering Amplitude, Phys. Letts **9**, 269 (1964).

[72] V. N. Gribov, I. Ya. Pomeranchuk and K. A. Ter-Martirosyan, A remark to the paper "Partial Waves Singularities near j-1 and High Energy Behaviour of the Elastic Scattering Amplitude", Phys. Letts **12**, 153 (1964).

[73] V. N. Gribov, I. Ya. Pomeranchuk and K. A. Ter-Martirosyan, Moving Branch Points in j-plane and Reggion Unitarity Conditions, YaF **2**, 361 (1965), Soviet JNP **2**, 258 (1966); Phys. Rev. **139**, 184 (1965); in: Problems of Physics of Elementary Particles, Erevan, AN ArmSSSR, 1964, p. 167; in: 12th Intern. Conf. on High Energy Physics, 1964, v. 1, Atomizdat, 1966, p. 363.

[74] B. L. Ioffe, I. Yu. Kobzarev and I. Ya. Pomeranchuk, Certain Consequences from Unitary Symmetry for Processes in which ω, φ, and f^0 Mesons Participate, JETP **48**, 375 (1965), Sov. Phys. JETP **21**, 247 (1965).

[75] L. B. Okun' and I. Ya. Pomeranchuk, "Shadow Universe" and Neutrino Experiment, JETP Letters **1**, No. 6, 28 (1965), transl. **1**, 167 (1965); Phys. Letts. **16**, 338 (1965).

[76] A. D. Dolgov, L. B. Okun', I. Ya. Pomeranchuk and V. V. Solov'ev, Electromagnetic Differences of Baryon Masses and SU_6 Symmetry, YaF **1**, 730 (1965), Soviet JNP **1**, 521 (1965); Phys. Lett. **15**, 84 (1965).

[77] V. N. Gribov, B. L. Ioffe, and I. Ya. Pomeranchuk, At which Distances Does Interaction Take Place at High Energy?, YaF **2**, 768 (1965), Soviet JNP **2**, 549 (1966).

[78] I. Yu. Kobzarev, L. B. Okun' and I. Ya. Pomeranchuk, Possibility of Experimentally Observing Mirror Particles, YaF **3**, 1154 (1966), Soviet JNP **3**, 837 (1966).

[79] V. N. Gribov, B. L. Ioffe and I. Ya. Pomeranchuk, Total Annihilation Cross Section of Electron-positron Pairs into Hadrons at High Energies (to be published).

Nuclear Physics and Reactor Theory

[80] A. I. Akhiezer and I. Ya. Pomeranchuk, Coherent Scattering of γ Rays by Nuclei, JETP **7**, 567 (1937); Phys. Z. Sowjetunion 10, 649 (1936).

[81] I. Pomeranchuk, Nuclear reactions inside stars, J. Phys. USSR 4, 285 (1941).

[82] A. Akhiezer and I. Pomeranchuk, Elastic Scattering of Fast Charged Particles by Nuclei, JETP **16**, 396 (1946); J. Phys. USSR 9, 471 (1945).

[83] A. I. Akhiezer and I. Ya. Pomeranchuk, Introduction to the Theory of Neutron Multiplying Systems (Reactors), ITÉF Report, 1947.

[84] A. Akhiezer and I. Pomeranchuk, Contribution to the Theory of Resonant Scattering of Particles, JETP 18, 603 (1948).

[85] I. Pomeranchuk, Remark on Zero-energy Particle Scattering, JETP 18, 1146 (1948).

[86] A. Akhiezer and I. Pomeranchuk, Certain Problems of Nuclear Theory, Gostekhizdat, 1948.

[87] I. I. Gurevich and I. Ya. Pomeranchuk, Theory of Resonant Absorption in Heterogeneous Systems (delivered at First Geneva Conference), AN SSSR, 1955.

Theory of Electromagnetic Processes

[88] I. Pomeranchuk, Maximum Energy that Primary Cosmic-ray Electrons Can Acquire on the Surface of the Earth as a Result of Radiation in the Earth's Magnetic Field, JETP 9, 915 (1939), J. Phys. USSR 2, 65 (1940).

[89] A. Migdal and I. Pomeranchuk, On the End of the Mesotron Trap in a Cloud Chamber, DAN SSSR 27, 653 (1940); Phys. Rev. 57, 934 (1940).

[90] D. D. Ivanenko and I. Ya. Pomeranchuk, Maximum Energy Attainable in a Betatron, DAN SSSR 44, 343 (1944).

[91] A. Kirpichev and I. Pomeranchuk, Screening of Effective Cross Sections for Bremsstrahlung and Pair Production with the Aid of Experimental Values of the Atom Form Factor, DAN SSSR 45, 301 (1944).

[92] L. Artsimovich and I. Pomeranchuk, Radiation of Fast Electrons in a Magnetic Field, JETP 16, 379 (1946); J. Phys. USSR 9, 267 (1945).

[93] I. Pomeranchuk, Radiation of Relativistic Electrons in a Magnetic Field, Byulleten' AN SSSR 10, 316 (1946).

[94] I. Pomeranchuk, Fluctuations of Polarization Ranges, JETP 18, 759 (1948).

[95] I. Pomeranchuk, Lifetime of Slow Positrons, JETP 19, 183 (1949).

[96] B. L. Ioffe and I. Ya. Pomeranchuk, Electrons Produced in the Capture of Pions by Atomic Levels, JETP 23, 123 (1952).

[97] L. D. Landau and I. Ya. Pomeranchuk, Limits of Applicability of the Theory of Bremsstrahlung of Electrons and Pair Production at High Energies, DAN SSSR 92, 535 (1953).

[98] L. D. Landau and I. Ya. Pomeranchuk, Electron-cascade Processes at Superhigh Energies, DAN SSSR 92, 735 (1953).

[99] G. M. Garibyan and I. Ya. Pomeranchuk, On the Limit of Applicability of the Theory of Transition Radiation, JETP 37, 1828 (1959), Sov. Phys. JETP 10, 1290 (1960).

Theory of Cosmic Rays

[100] I. Pomeranchuk and A. Kirpichev, Spectrum of Soft Component in Air at High Energies, DAN SSSR 41, 19 (1943).

[101] I. Pomeranchuk, On Interpretation of Experimental Data on Large Cascade Showers, JETP 14, 252 (1944); J. Phys. USSR 8, 17 (1944).

[102] A. Kirpichev and I. Pomeranchuk, Contribution to the Theory Effects in Cosmic Rays, DAN SSSR 42, 396 (1944).

Solid State Theory

[103] L. Landau and I. Pomeranchuk, On the Properties of Metals at Very Low Temperatures, JETP 7, 379 (1937); Phys. Z. Sowjetunion 10, 649 (1936).

[104] I. Pomeranchuk, On the Scattering of Slow Neutrons in a Crystal Lattice, JETP 8, 894 (1938); Phys. Z. Sowjetunion 13, 65 (1938).

[105] I. Pomeranchuk, Crystal Field in Superconductors of Small Dimensions, JETP 8, 1096 (1938).

[106] B. Davydov and I. Pomeranchuk, Influence of Magnetic Field on the Electric Conductivity of Single-crystal Bismuth at Low Temperatures, JETP 9, 1294 (1939), J. Phys. USSR 2, 147 (1940).

[107] I. Pomeranchuk, Thermal Conductivity of Paramagnetic Dielectrics at Low Temperatures, JETP 11, 226 (1941); J. Phys. USSR 4, 356 (1941).

[108] I. Pomeranchuk, Thermal Conductivity of Dielectrics at Temperatures Exceeding the Debye Temperature, JETP 11, 246 (1941); J. Phys. USSR 4, 259 (1941).

[109] I. Ya. Pomeranchuk, Absorption of Sound in a Dielectric, JETP 11, 455 (1941); J. Phys. USSR 4, 529 (1941).

[110] I. Pomeranchuk, On the thermal conductivity of dielectrics, Phys. Rev. 60, 820 (1941).

[111] I. Ya. Pomeranchuk, Thermal Conductivity of Dielectrics at Temperatures Below the Debye Temperature, JETP 12, 245 (1942); J. Phys. USSR 6, 225 (1942).

[112] I. Pomeranchuk, Thermal Conductivity of Dielectrics at Temperatures Lower than that of Debye, J. Phys. USSR 6, 237 (1942).

[113] I. Pomeranchuk, Thermal Conductivity of Dielectrics at High Temperatures, JETP 12, 419 (1942).

[114] I. Pomeranchuk, On the Theory of Absorption of Infrared Rays in Crystals Having a Symmetry Center, JETP 13, 428 (1943).

[115] A. Akhiezer and I. Pomeranchuk, Thermal Equilibrium Between Spins and the Lattice, JETP 14, 342 (1944), J. Phys. USSR 8, 206 (1944).

[116] A. Akhieser and I. Pomeranchuk, On the Heat Conductivity of Salts in the Magnetic Cooling Method, J. Phys. USSR 8, 216 (1944).

[117] A. Akhiezer and I. Pomeranchuk, On the Thermal Conductivity of Bismuth, JETP 15, 587 (1945).

[118] A. Akhiezer and I. Pomeranchuk, On the Scattering of Slow Neutrons in Crystals, JETP 17, 769 (1947).

[119] A. Akhiezer and I. Pomeranchuk, Neutron Refraction, JETP 18, 475 (1948).

[120] A. I. Akhiezer and I. Ya. Pomeranchuk, Paramagnetic Dispersion, DAN SSSR 87, 914 (1952).

[121] I. Ya. Pomeranchuk, Isotopic Effect in the Residual Resistance of Metals, JETP **35**, 992 (1958), Sov. Phys.-JETP **8**, 693 (1959).

[122] A. I. Akhiezer and I. Ya. Pomeranchuk, Interaction between Conduction Electrons in Ferromagnets, JETP **36**, 859 (1959), Sov. Phys. JETP **9**, 605 (1959).

Theory of Quantum Liquids

[123] A. Akhiezer and I. Pomeranchuk, On the Scattering of Low Energy Neutrons in Helium II, J. Phys. USSR **9**, 461 (1945).

[124] A. Akhiezer and I. Pomeranchuk, Scattering of Neutrons with Energy of Several Degrees in Liquid Helium II, JETP **16**, 396 (1946).

[125] L. D. Landau and I. Ya. Pomeranchuk, Motion of Extraneous Particles in Helium II, DAN SSSR **59**, 669 (1948).

[126] I. Pomeranchuk, Influence of Impurities on the Thermodynamic Properties and the Speed of Second Sound in Helium II, JETP **19**, 42 (1949).

[127] I. Ya. Pomeranchuk, Contribution to the theory of Liquid He^3, JETP **20**, 919 (1950).

[128] I. Ya. Pomeranchuk, Stability of a Fermi Liquid, JETP **35**, 524 (1958), Sov. Phys.-JETP **8**, 361 (1959).

[129] A. I. Akhiezer, I. A. Akhiezer and I. Ya. Pomeranchuk, On scattering of Slow Neutrons in à Fermi Liquid, Nucl. Phys. 40, 139 (1963).

Translated by J. G. Adashko