International seminar on semiclassical description of atomic and nuclear collisions (Held at the Niels Bohr Institute, Copenhagen, 24–31 March 1985)

S. P. Kapitsa and A. B. Kurepin
Usp. Fiz. Nauk **148**, 381–383 (February 1986)

The convening of the International Seminar on Semiclassical Description of Atomic and Nuclear Collisions is the first of three principal activities undertaken by the Niels Bohr Institute on the occasion of the 100th anniversary of the birth of Niels Bohr (7 October 1985). The subject matter of the seminar was chosen to correspond to the first work of Niels Bohr, which was begun 50–70 years ago. Since that time the theoretical description of atomic and nuclear collisions by means of semiclassical ideas has made great progress. A particularly great advance in the development of the theory has occurred during the last 20–25 years.

An intensive use of quasiclassical methods is observed not only in the problems of atomic physics, first formulated by Niels Bohr, but also in the problems of collision of nuclei with nuclei. The latter problems have arisen comparatively recently and have been due to the development of experimental studies, which have been carried on and are being extensively continued at the present time with use of the beams of heavy ions from tandem electrostatic accelerators, isochronous cyclotrons, synchrocyclotrons, and linear accelerators. Interest in the semiclassical description of the collisions of atoms and nuclei is explained primarily by the fact that a better understanding of the processes is achieved, since the concept of the trajectories of the particles is introduced, and also as a consequence of the fact that here qualitatively new possibilities are predicted for the temporal development of collision processes, for example, the appearance of orbiting, rainbow scattering, and so forth.

At the same time it must be noted that questions of collision of atoms and molecules apply mainly to problems that are the subject of chemistry, while the collision of nuclei with nuclei is now one of the most promising directions of nuclear physics. There is in addition another very important aspect: the passage of heavy particles and electrons through matter. Of particular interest at the present time is the passage of particles through crystals and the channeling effects that arise. These problems are closely related to solid state physics. The diversity that we have mentioned in the phenomena included in the subject matter of the seminar has resulted also in a different nature of the principal activity of the participants of the seminar, who for the most part are not well acquainted with the state of research in the neighboring regions of atomic or nuclear collisions. Therefore, the intention of the organizers of the seminar has been that this extensive undertaking should facilitate the development of scientific contacts between physicists and chemists and the discovery of common problems and methods of their solution.

It must also be taken into consideration that, in spite of the fact that all of the papers, both theoretical and experimental, are devoted to fundamental problems of atomic and nuclear physics, research carried out in these fields has major significance in many areas of physics. For example, studies of atomic collisions provide the necessary theoretical and experimental material for the development of plasma physics and solid state physics. Studies of nucleus-nucleus collisions are to a significant degree directed toward the search for methods of synthesis of superheavy elements. With increase of the energy of accelerated particles, new possibilities appear for the investigation of phase transitions in nuclear matter.

Only plenary sessions were held in the seminar. The program was constructed so that each morning was occupied by a review paper covering the common quantum-mechanical principles of description of atomic and nuclear collisions. These are the reports on the classical limit of quantum mechanics by William Miller of Berkeley, on the method of functional integrals by S. Levit of MIT, on the WKB approximation by D. Brink of Oxford, and on the density matrix in phase space by Fredrik Zachariasen of the California Institute of Technology, presented by J. Dalem of the Danish Technical University.

Then during each day some problem of collision physics was discussed; here half of the papers were on the physics of atomic collisions and half on the physics of nuclear collisions, usually three or four papers each. Problems of elastic and inelastic collisions of atoms and nuclei were discussed, and also collisions with rescattering of particles after the interaction, including the capture of electrons by atoms, and complex collisions. The last day was devoted to the passage of atomic particles through matter, for which work of the Aarhus University in Denmark is very well known. The principal rapporteur was J. Lindhard from this university, who is known for his pioneering studies in channeling effects.

The papers given by the physicists from the USA concerned mainly nuclear collisions and general questions of quantum mechanics. The principal paper was the report of the well known specialist W. Swiatecki from the Lawrence Laboratory at Berkeley on friction in nuclear collisions; he

 0038-5670/86/020210-02$01.80

reviewed methods of theoretical description of nuclear collisions by means of the introduction of classical characteristics of the surface interaction of nuclei. Also taking part in the seminar was one of the best known specialists in atomic theory, Ugo Fano of the James Franck Institute at the University of Chicago. Fano's contribution to development of the theory of interaction of photons and electrons with atoms is well known; he has devoted more than 40 years to this subject. His paper at the seminar concerned an important question of modern quantum theory: application of the quasiclassical Wentzel-Kramers-Brillouin method to solution of the multidimensional Schrödinger equation. This equation describes complicated cases of behavior of an electron in Coulomb and magnetic fields or of two electrons in a Coulomb field. While the WKB method in the one-dimensional case is very convenient and therefore enjoys great popularity, in the multidimensional case its use encounters great difficulties. Fano proposed an original procedure based on expansion of the solution in a set of wave functions in the separable approximation.

We must single out also the report of the well known American specialist on quantum chemistry William Miller from the University of California at Berkeley, who opened the seminar. His paper was devoted to the classical limit of quantum mechanics. In it he discussed the basic questions of the semiclassical method in collision theory: obtaining the Boltzmann operator, introduction of a potential for description of the trajectory, the formalism of semiclassical transport theory, and the form of the potential for the surface interaction of atomic systems.

The West German physicists presented a basic paper on the theory of interaction of atomic systems at low energy. J. P. Toennies of the Max Planck Institute at Göttingen discussed two problems that are very important in the contemporary development of the theory. These are the occurrence of rainbow scattering in the collision of rather heavy atoms and molecules such as lithium and nitrogen or carbon monoxide, and also argon and oxygen, and the influence of the structure of the molecule on the form of the angular distribution. Recently considerable attention has been devoted to the study of optical analogies in the scattering process. J. P. Toennies gave examples of the use of Fraunhofer diffraction in description of the inelastic scattering of helium atoms by nitrogen at energies of a few tens of MeV in analogy with the inelastic scattering of α particles by zinc nuclei at 40 MeV carried out by S. I. Drozdov and E. V. Inopin, and subsequently by the American physicist J. Blair. Similar methods are now used also for study of scattering of atoms at the surface of a crystal.

The Niels Bohr Institute presented the report of one of its scientific directors A. Winther on the theory of nuclear transfer reactions. He reviewed a long cycle of studies carried out by Winther and his collaborators in recent years. The reaction cross sections and polarizations have been calculated on the basis of the quasiclassical theory of transfer reactions induced by heavy ions. Two-nucleon transfer reactions have been considered in the greatest detail. Various experimentally observed effects were described such as the rise of the cross section at large angles for the elastic scattering channel. It was shown that two-nucleon transfer reactions permit one to obtain nuclear states of the residual nuclei with angular momenta up to 20 in the rare earth region and up to 30 in the actinide region.

The problem of the deep inelastic interaction of heavy nuclei at energies of a few MeV per nucleon was the subject of the paper by J. Huizenga of the University of Rochester. This case of nuclear collisions occupies an intermediate situation between reactions occurring through a compound nucleus and quasielastic processes. An analysis was given for the collisions of very heavy nuclei such as bismuth and xenon. By introduction of a potential, cross sections were calculated as a function of the mass number and charge of the nuclei and their energy, and also estimates were given of the deexcitation and of the emission of light nuclei. The paper discussed also the possibility of construction of a dynamic model of the the interaction based on transport theory.

In the last session of the seminar there was a general discussion on the problems that had been touched. The discussion was led by the chairman of the organizing committee, A. Winther. Several questions of the development of the theory of the semiclassical description of collisions were discussed: the applicability of the WKB approximation, barrier transmission, the influence of zero-point oscillations, and also new applications of the time-dependent Hartree-Fock method.

The seminar was carried on in an atmosphere of friendship and collaboration, which constantly reminded its participants of Niels Bohr not only as one of the founders of modern physics, but also as the creator of one of the most experienced physics groups.

Translated by Clark S. Robinson