Leonid Veniaminovich Keldysh (On his sixtieth birthday)

A. F. Andreev, N. G. Basov, V. L. Ginzburg, A. V. Gurevich, B. B. Kadomtsev, D. A. Kirzhinits, Yu. V. Kopaev, Yu. A. Osip'yan, A. M. Prokhorov, E. L. Feĭnberg, and E. S. Fradkin

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April 7, 1991 marks the 60th birthday of Leonid Veniaminovich Keldysh.

Solid state physics, especially semiconductor physics, is fortunate that the principal achievements of Leonid Veniaminovich Keldysh and his plans for the future lie in this area.

In 1954, L. V. Keldysh graduated in physics from Moscow State University and began his post-graduate studies under V. L. Ginzburg at the P. N. Lebedev Physics Institute of the Academy of Sciences of the USSR in Moscow. Even his first works, devoted to the behavior of the electrons of a semiconductor in a strong electric field, were classic. In an electric field varying slowly in space (compared with the crystal field) the energies of the Bloch electrons from different bands can coincide at spatially separated points. In some region of space for a given energy an electron must have an imaginary quasimomentum, i.e., this state is forbidden from a classical point of view. It was shown by L. V. Keldysh that in such a situation tunneling is possible. The band gap plays the role of barrier height, and tunneling through the barrier corresponds to the transition of an electron from the filled valence band into the empty conduction band (1957).

A few years later this prediction of a detailed quantitative coincidence was confirmed experimentally. This effect has found broad practical application in tunnel diodes. He showed in this work that if the extrema of the bands, between which tunneling occurs, do not coincide in quasimomentum space, then the tunneling is accompanied by phonon absorption or emission. Thus, this work was the first concerning a microscopic validation of macroscopic dissipative tunneling now being widely investigated.

In a subsequent paper (1958) it was shown that a result of this same tunneling effect is that the threshold of band-to-band absorption of an electromagnetic field is displaced toward lower frequencies (the Franz–Keldysh effect). This effect has found widest application in modulation spectroscopy of semiconductors (electromodulation), and is also used to tune the lasing frequency of semiconductor lasers. L. V. Keldysh was awarded the M. V. Lomonosov prize for this work.

Subsequently (1964) L. V. Keldysh showed that the multiquantum photoeffect and the high-frequency tunnel effect are different limiting cases of the same process, and he constructed a general theory explaining many features of the behavior of atoms in solids in strong electromagnetic fields.

The work of L. V. Keldysh on deep impurity states in semiconductors (1963) made it possible to answer two fundamental questions: 1) Why, for example, does a bound electron state appear at a negatively charged impurity center (multiply charged impurities), and 2) why are some impurities very active recombination centers? In this work he took correct account of the effect of both bands (the valence and conduction bands) on formation of the impurity state.

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The answer to the first question was that because of the contribution of valence band states having a negative effective mass the sign of the kinetic energy is reversed.

The answer to the second question was that such recombination centers correspond to the situation of a particle incident on the center.

A subsequent series of papers was devoted to an investigation of the distribution function of band electrons in a strong electric field. A general formula was obtained that explains in different limiting cases the different types of observed field dependences of the impact ionization coefficient. To describe situations when the self-consistent variation of states and their distribution function must be taken into account (by analogy with the equilibrium theory of a Fermi liquid), L. V. Keldysh developed (1964) a fundamental diagrammatic technique for highly nonequilibrium processes.

In 1962 L. V. Keldysh suggested using spatially periodic fields to control the electron spectrum and electron properties of crystals. This paper marked the initiation of a field of solid state physics that is being vigorously developed now and is related to the artificial formation of superlattices, which are finding ever wider practical application (band structure engineering). In 1974 L. V. Keldysh was awarded the Lenin Prize.

The next stage in the scientific career of L. V. Keldysh

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was involved with a study of collective phenomena in solids. At this same time he began to form his own scientific group. Since 1969 L. V. Keldysh has been Professor and since 1978 Department Director at Moscow State University.

As a result of active experimental studies of metal–insulator (or semiconductor) phase transitions the so-called exciton insulator model was proposed by him and Yu. V. Kopaev (1964), in which electron-hole pairs, causing a phase transition in the insulator, appear even for an arbitrarily Coulomb interaction. The terms of the interaction, responsible for the band-to-band transfer of electrons, fix the phase of the corresponding order parameter (making the phase transition a transition of the first kind), and the spectrum of collective excitations is transformed into a slit spectrum (instead of an acoustic Goldstone spectrum) (work with R. R. Guseĭnov, 1972). Various ordered states (ferroelectric, antiferromagnetic, ferromagnetic, current) are described by this model. Since similar states are described in the other limiting case of a strong interaction (the Hubbard model), the case that is intermediate in terms of interaction is described qualitatively.

The next series of papers was devoted to a study of the collective properties of nonequilibrium electrons and holes.

In 1968 he investigated (with A. N. Kozlov) the Bose condensation condition and showed the prominent role of the non-Bose nature of excitons on their final concentration.

In work during 1971 L. V. Keldysh gave a consistent microscopic derivation of the Ginzburg–Landau equations that describe a Bose condensate of nonequilibrium excitons. Despite the finite lifetime of electrons and holes, nondissipative transport of the excitation energy is possible.

In 1968 L. V. Keldysh showed that when there are a large number of valleys for electrons and holes (the number of extrema in the conduction band and in the valence band, respectively), there is a tendency for stratification–the formation of a drop of electron-hole liquid in the exciton gas. In the limit of an infinite number of valleys the very simple description in the random phase approximation of the state of the electron-hole drop is rigorous (a paper in 1976 with E. A. Andryushin, V. S. Babichenko, T. A. Onishchenko, and A. P. Silin).

The theoretical prediction of the formation of drops of electron-hole liquid and their properties have been thoroughly confirmed by numerous experiments. In 1974 the European Physics Society Prize was awarded to L. V. Keldysh and M. Voos, V. S. Bagaev and Ya. E. Pokrovskiĭ for this work.

L. V. Keldysh has made fundamental contributions in the area of nonlinear coherent optics. He predicted that in the presence of Raman or Mandel'shtam–Brillouin Stokes scattering there exists a new type of collective excitation called the phonoriton–a bound state of polariton and phonon (paper in 1983 with A. L. Ivanov). Under anti-Stokes scattering conditions he predicted a phase transition into a coherent phonoriton state and he investigated the properties of this state (paper with S. G. Tikhodeev in 1986).

L. V. Keldysh's contribution both at the stage of stating a problem and also frequently in finding the solution has been a determining factor in a vast number of papers published by his students.

We must point out a characteristic of L. V. Keldysh, surprising for our time, which has typified him since the very beginning of his scientific career. Each paper published by him is subjected to critical faultfinding by him long after it has been sent to the printer.

All of his scientific life preceding this anniversary inspires confidence that under the direction of Leonid Veniaminovich Keldysh FIAN will be filled with the spirit for a wholehearted search for truth. We are confident that L. V. Keldysh will continue to surprise us many times with brilliant ideas.

Translated by Eugene R. Heath