Leonid Keldysh – one of the most influential theoretical physicists of the 20th century – passed away in November 2016. Keldysh is best known for the diagrammatic formulation of real-time (nonequilibrium) Green functions theory and for the theory of strong field ionization of atoms. Both theories profoundly changed large areas of theoretical physics and stimulated important experiments. Both these discoveries emerged almost simultaneously – like Einstein, also Keldysh had his *annus mirabilis* – the year 1964. But the list of his theoretical developments is much broader and is briefly reviewed here.

Keldysh’s heritage includes 77 scientific publications \[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77\], that reflect the broad range of topics, Keldysh was interested in and how this interest evolved over time. His two most influential papers on real time Green Functions \[12\] and strong field ionization \[13\] were published in 1964 in the Zhurnal Teoreticheskoi i Eksperimentalnoi Fiziki (abbreviated ZhETF, the English translation is being published as JETP or Soviet Physics JETP) and collected about 3300 and 6000 citations, respectively\[13\]. In fact, these two papers were written almost at the same time. They were submitted by Keldysh to the journal on April 23 and May 23, 1964, respectively, making the year 1964 Keldysh’s *annus mirabilis*. All articles of L.V. Keldysh are listed in chronological order in the reference section at the end of this paper.

Also, the activity of Keldysh in support of Russian science, in general, and the Academy of Sciences, in particular, is documented in 7 articles published between 1992 and 1999, \[78,79,80,81,82,83,84\]. They are interesting historical documents in their own but also show that Keldysh was speaking up publicly when he thought this is necessary, often together with other leading Russian colleagues. Some information on the often difficult political environment is contained in the biographical notes in Sec. 2. Moreover, Keldysh published a remarkable number of 61 short notes in honor of leading Russian physicists – a special tradition in Soviet and Russian science. These articles include 42 birthday congratulations and 29 obituaries.

Finally, we also include some remarks on Keldysh’s students and Keldysh’s work as a mentor, in Sec. 5.
2 Biographical notes

Leonid Keldysh was born in Moscow on 7 April 1931 in a family of scientists. His mother, Lyudmila Vsevolodovna Keldysh, was a leading Soviet mathematician, her brother, an applied mathematician, Mstislav Vsevolodovich Keldysh was one of the leaders of the Soviet space program, later becoming the President of the USSR Academy of Sciences. Leonid’s step father was Petr Sergeevich Novikov, a full member of the Academy and also a leading mathematician, while Leonid’s younger step brother, Sergei Petrovich Novikov, also becoming a mathematician and Academy member, was later awarded the Fields medal. But Leonid’s choice was theoretical physics.

In 1948 Keldysh enrolled in the Physics Department of Moscow State Lomonosov University (MGU), where he graduated in 1954 (attending also courses at the Department of mechanics and mathematics for an extra year). After this he started to work at the Theoretical Physics Department of the P.N. Lebedev Physics Institute (LPI) of the Academy of Sciences, which remained his work place until the end of his life. His scientific supervisor at LPI was Vitaly Lazarevich Ginzburg, and the Theoretical Department at that time was headed by Igor Evgenievich Tamm (both later becoming Nobel prize winners). However, since these early years, Leonid was essentially a self–made man in science.

In his early works (1957–1958) Keldysh developed a consistent theory of phonon-assisted tunneling in semiconductors which was immediately recognized by the semiconductor community. His most famous work of this period was devoted to the calculation of the electric field-induced shift of the absorption edge in semiconductors, what is now called the Franz–Keldysh effect [86], see Sec. 4.3.1. In the early 1960s he proposed to use spatial modulation of the lattice to create an artificial band structure [7]. This idea was later realized in semiconductor superlattices. He also developed an original theory of core levels in semiconductors [9]. One of his most famous works of this period was the 1964 theory of tunnel and (multi-)photon ionization of atoms by intense electromagnetic waves [13] that became the starting point for the entire field of intense laser–matter interaction, including atoms, ions, molecules, plasmas and solids, cf. Sec. 4.1. This field has recently been reviewed in Ref. [87], where it is concluded that the success behind the theory is that it precisely fulfills the criterion “making things as simple as possible, but not simpler”. This feature is characteristic of many of Keldysh’s other influential papers.

Leonid Keldysh started working in science during a period when quantum field theory methods were popular and successfully applied in condensed matter physics. Here he made his most famous contribution with his 1964 work on a general diagram technique for nonequilibrium processes [12]. Introducing Green functions with time–ordering along what is today known as the (Schwinger)-Keldysh time contour, he was able to construct the standard Feynman diagrams for these Green functions at finite temperatures and for general nonequilibrium states, see Sec. 3.
Strange enough, even at that time, ten years after starting his work, he had not yet been awarded any higher scientific degree. However, when he finally submitted the Candidate of Science (PhD) thesis, in 1965, he was immediately awarded the degree of Doctor of Science (similar to habilitation in Germany). In 1968 he was elected corresponding member of the USSR Academy of Sciences, becoming a full member in 1976.

Since 1964 Keldysh’s interests moved to semiconductors. In his work with Yu.V. Kopaev [15] he introduced the new concept of an excitonic insulator and to laser excited nonequilibrium exciton systems, exciton superfluidity [20] and their ionization into an electron–hole quantum liquid of electron–hole droplets, for details see Sec. 4.2.

Since 1965 Keldysh was a professor at MGU heading the chair of quantum radiophysics (1978-2001). He had many PhD students, a number of which later became famous theoreticians, professors and members of the Russian Academy of Sciences, see Sec. [5]. He was member of editorial boards of the leading Russian physics journals and served as Editor in Chief of Physics Uspekhi, from 2009 to 2016. Keldysh was awarded numerous prizes, including the Lenin prize (1974), the Hewlett–Packard Prize (1975), the Alexander von Humboldt Prize (1994), the Rusnanoprize (2009), the Eugene Feinberg Memorial Medal (2011), the Pomeranchuk Prize (2014) and the Grand Lomonosov Gold Medal of the Russian Academy of Sciences (2015). He was elected foreign member of the US National Academy of Sciences (1995) and became a Fellow of the American Physical Society in 1996.

In the late 1980s Keldysh had to perform various administrative duties, which he actually did not like at all, but considered impossible to reject during this difficult period for Russian Science. These included the head of the Theoretical Physics Department and the director of the Lebedev Institute (1989–1994) and also the position of a Secretary of the General Physics Department of the Russian Academy of Sciences (1991–1996). During this period he lived in his own way, never conforming to external circumstances. He always was a highly independent person, and it was impossible to persuade him to take a decision he did not agree with. He was among the leading RAS members who strictly rejected the Government–proposed reform of the Academy in 2013, becoming a member of the influential “Club of July 1” within the RAS, opposing this reform.

3 Nonequilibrium (Real-time or Keldysh) Green Functions (NEGF) Judging by its impact on a huge number of fields Keldysh’s Real-time Green functions theory is, without question, his most important discovery, and we address it in some more detail.

3.1 The story of NEGF Quantum many-body systems have been described by many different approaches including wave function methods, reduced density operators (quantum BBGKY-hierarchy) of Bogolyubov, Krikelwood and others, e.g. [88] as well as Green functions and Feynman diagrams by Schwinger, Dyson and Feynman.
Following the results for the ground state soon the extension to thermodynamic equilibrium was developed in the 1950s by Matsubara, Kubo as well as Abrikosov, Gorkov, Dzyaloshinski in the U.S.S.R. which led to the concept of imaginary-time Green functions. The idea to rewrite the canonical density operator in thermodynamic equilibrium as a quantum-mechanical evolution operator, but in imaginary time, was then quite popular in a number of fields, including Feynman’s path integral concept, so that step was rather natural.

However, the extension of the technique from thermodynamic equilibrium to arbitrary nonequilibrium situations is a huge step that is far less straightforward, and it took more time to develop. These developments occurred almost independently in the U.S. and in the U.S.S.R. The works in the U.S. were mostly due to Martin and Schwinger who derived the generalization of the BBGY-hierarchy to the case of many-time Green functions [68], and Baym and Kadanoff who derived and analyzed the generalization of the Boltzmann equation that includes memory effects [90]. These developments were reviewed in detail by Paul Martin and Gordon Baym in their lectures at the first Nonequilibrium Green Functions conference in Rostock, Germany, in 1999, cf. Refs. [91,92]. The Russian developments in the field of Nonequilibrium Green functions are due solely to Leonid Keldysh and were published in his seminal paper [12] where he introduced the “round trip time contour” – a small but ingenious mathematical trick – that allowed him to rigorously extend Feynman’s diagram technique to nonequilibrium. The Russian developments in thermodynamic and Nonequilibrium Green functions were reviewed by Alex Abrikosov [93] and Leonid Keldysh [69], respectively. The latter article is reprinted as a supplement to this paper.

### 3.2 The PNGF conferences and Leonid Keldysh

Interestingly, after writing his paper introducing NEGF in 1964, Keldysh did not actively continue these developments (the same was true for Baym and Kadanoff). So it must have been a surprise for them that they were in 1999 invited to a conference entitled “Kadanoff-Baym equations–Progress and Perspectives for Many-Body Theory”, 35 years after the original developments. In fact, in the 1970s and 1980s NEGF were used only by a few groups worldwide but the activities increased significantly in the 1990s when NEGF methods were used in semiconductor optics and various groups learned to directly solve the Keldysh-Kadanoff-Baym equations (KBE) on modern computers, following the pioneering work of Danielewicz [95] on nuclear collisions. Not surprisingly, many theorists [91] expected that these equations would lead to breakthroughs in many fields which indeed turned out to be the case, see Sec. 3.3.

At the same time, the lengthy title of the conference in 1999 reflects some confusion in the community about the different contributions of the American and Russian founders of the theory and about the priorities. Even Baym was under the impression that Keldysh’s work of 1964 was a follow up to their book [90], as he pointed out in his conference talk in 1999 and in the proceedings [92]. However, this was an incorrect assumption. Not surprisingly, Keldysh – who could not participate in the 1999 conference – was very upset when he became aware of Baym’s article. He then took the opportunity to attend the second conference, “Progress in Nonequilibrium Functions (PNGF) II” in Dresden in 2002 and, in his lecture, to “straighten” things out. For everybody who uses NEGF today or will do so in the years to come, this turned out to be a very lucky case, because Keldysh summarized in some detail and in his honest style how his ideas emerged and who influenced him. We are lucky that he published his recollections in the conference book [101], and his article is reprinted as a supplement to this paper. A photo showing Leonid Keldysh at the PNGF II together with, among others, Alex Abrikosov, Paweł Danielewicz and Paul Martin is shown in Fig. 6.

The success story of nonequilibrium Green functions and the tremendous impact of Keldysh’s paper [12] is clearly reflected in the next meetings of the conference series and their proceedings [96,102,103,104] culminating in the present issue of the proceedings of the 2018 conference.

### 3.3 Current research fields based on NEGF

During the last three decades NEGF have seen a dramatic increase in attention. This is mostly due to the increase in computing capabilities that have made direct solutions of the Keldysh-Kadanoff-Baym equations possible. Applications have been developed for a large number of fields where many-body effects, correlations and non-quasiparticle behavior are of relevance. This includes transport in metals [105], semiconductor optics and transport [106], nanostructures [107], atoms and molecules [108].

3 Here we should mention, in particular, W. Schäfer [96,97], D. Kremp [98,99], H. Haug [100] and K. Henneberger in Germany and their schools.
molecules [107,108], plasma physics [109,110], nuclear matter [111,112], cosmology [113,114], transport properties of strongly correlated cold fermionic atoms [115,116], among others.

4 Other research topics of L.V. Keldysh

4.1 Strong Field Ionization

Cited more than 5500 times, Keldysh’s paper [13] presented the first quantum theory of the ionization of an atom by an intense laser field. The paper introduced optical tunneling, multi-photon ionization, and above-threshold ionization, experimentally observed about 15 years later, e.g. [117]. Keldysh presented the first nonlinear quantum-mechanical calculation of the ionization probability of an atom in a strong electromagnetic field. Starting from the time-dependent bound state wave function (we follow the notation of Ref. [87])

\[ \Psi_0(t) = \psi_0(r)e^{iI_p t/\hbar}\]

he computes the transition probability amplitude of the electron into a time-dependent continuum state in the presence of the field (i.e. a Volkov state [118]),

\[ M(p) = -\frac{i}{\hbar} \int_{-\infty}^{\infty} dt \langle \Psi_p(t)|V_{\text{int}}(t)|\Psi_0(t)\rangle, \]

\[ (1) \]

where \( I_p \) denotes the ionization potential, \( p \) the canonical momentum, and \( V_{\text{int}} \) the interaction potential of the electron with the field. Note that the explicit forms of \( \Psi_p \) and \( V_{\text{int}} \) depend on the chosen gauge, so the analysis requires some care. Indeed, many suggested modifications or improvements of Keldysh’s work led to gauge-dependent results giving rise to debates in the community, for details see [87]. The momentum distribution of the photoelectrons is then

\[ dW(p) = |M(p)|^2|dp|, \]

and the total ionization probability is the momentum integral of \( dW \). Using the dipole approximation for the field and neglecting Coulomb interaction and relativistic effects on \( \Psi_p \), Keldysh was able to obtain closed expressions for the ionization probability. The result contains an important dimensionless parameter – the “Keldysh parameter”,

\[ \gamma = \sqrt{2mI_p \frac{\omega}{eE_0}}, \]

\[ (2) \]

which determines the boundary between multiphoton and tunneling regimes. Here \( \omega \) and \( E_0 \) are, respectively, the frequency and amplitude of the exciting electric field. The Keldysh parameter describes the ratio of the characteristic momentum of the electron in the bound state, \( \sqrt{2mI_p} \),
to the momentum the electron gains from the field, $eE_0/\omega$. For $\gamma < 1$ ($\gamma > 1$), ionization is dominated by the tunnel (multiphoton) mechanism. In case of a monochromatic field and $\gamma > 1$, multiphoton absorption is possible if the atom absorbs at least

$$N_{\text{min}} = \frac{I_p + U_p}{\hbar \omega} + 1$$

photons which includes the average kinetic energy of the free electron in the field ("ponderomotive potential"), $U_p = (eE_0)^2/(4\pi\hbar^2)$. If the photon number exceeds $N_{\text{min}}$, ionization will lead to distinct peaks in the photo-electron energy spectrum – which has been called "above threshold ionization" – and has been accurately verified experimentally. With the dramatic progress in laser technology and the availability of coherent radiation sources from the infrared range to x-rays, these effects have achieved fundamental importance in countless fields.

Keldysh’s theory triggered a tremendous wave of further improvements of the theory that include Coulomb interaction, relativistic effects or the field-induced modification of the bound states (Stark effect). The analysis of ionization processes was extended to more complex atoms, molecules and semiconductors, and similar approaches were developed for relativistic effects such as pair creation (Schwinger mechanism). For additional information and references, the reader is referred to the review [87].

### 4.2 Excitons and electron-hole systems

Keldysh made important contributions to semiconductor physics. He was early on interested in the many–exciton problem in semiconductors. In his work with Yu.V. Kopaev [15] he introduced the new concept of an excitonic insulator. Actually this was a new mechanism of a metal–insulator transition. In later works by Keldysh and his collaborators it was shown conclusively, that there are no superfluidity properties in this model [27], as was initially suspected by some authors, and he moved to the study nonequilibrium systems of excitons, appearing under intense laser pumping of semiconductors, where superfluidity of excitons was shown to be possible [20]. However at that time (1968) Keldysh realized, that in most semiconductors (with multiple bands) the nonequilibrium system of many excitons actually transforms into an electron–hole quantum liquid (where excitons are ionized), forming electron–hole droplets. Interestingly enough, this idea was expressed only in his summary talk at the Moscow International Conference on Semiconductors [119] and was not published anywhere for a rather long time. However, it immediately stimulated experimental studies, and electron–hole droplets were soon discovered, leading to many further experimental and theoretical works on this new state of matter. Essentially, he supervised these works around the Soviet Union, continuing to introduce new concepts, such as the phonon “wind” in the system of electron–hole droplets [35]. An overview of the field of electron-hole droplets can be found in the review [120]. Electron-hole droplet formation was also verified in ab initio quantum Monte Carlo simulations [121]. The problem of limited life time of electron-hole pairs in optically excited semiconductors can be overcome with indirect excitons predicted by Lozovik and co-workers [122] which have interesting superfluidity properties [123].

### 4.3 Further research results

Even though Keldysh is mainly famous for real-time Green functions, strong-field ionization and the theory of excitons, he has made important contributions to many other fields.

#### 4.3.1 Franz-Keldysh effect

It was a natural question to ask whether the Franz-Keldysh effect (the shift of the absorption edge due to an applied static electric field) could be extended to a situation where the absorbing sample was placed in a time-dependent field. Indeed, early theoretical work addressed some aspects of this situation [124, 125]. Experimentally, however, sufficiently strong time-dependent fields were not available until the first free-electron lasers started operation. A detailed study was published in Ref. [126], where the excitonic absorption of a quantum well system was studied as a function of the frequency of the impinging strong THz field emanating from the Santa Barbara free-electron laser. The theory developed for this situation agreed very well with the observations. The theory combines three concepts in whose development the pioneering ideas by Keldysh were crucial: strong field effects in semiconductors, excitonic dynamics, and nonequilibrium Green’s functions. It is remarkable that all three ingredients originate from the same author.

#### 4.3.2 Transport in mesoscopic systems

The scattering theory of transport, developed by Landauer and Büttiker [127, 128], which expresses the conductance of a mesoscopic sample in terms of its transmission properties, is – despite of its huge success and importance – only valid for systems where electron-electron or electron-phonon interactions can be ignored. The Keldysh diagram technique, which allows for a systematic treatment of interactions, is particularly well-suited for deriving extensions of the Landauer-Büttiker formalism. The Keldysh technique, as applied to transport physics, was introduced in the Western literature in an important series of papers by Caroli, Combescot, and co-workers [129, 130, 131, 132]. These papers were mainly concerned with tunneling through a single barrier (including interactions with localized states and phonons in the barrier), but a real breakthrough occurred in 1992, when Meir and Wingreen showed [133] that the calculation of the conductance through a quantum dot with arbitrary interactions could be formulated in a similar manner. Literally thousands of papers have examined transport in situations where interactions are important.
One example is the tunneling of electrons between a tip and a metal through a single adsorbed molecule (or atom) in a scanning tunneling microscope. The Keldysh technique provides an elegant way to describe the inelastic stationary electron tunneling with emission and absorption of vibrational excitations of the molecule, interactions with the phonon baths in the substrate and tip, as well as the overheating of the molecule and its resulting motion – hopping or rotation \cite{134,135,136,137,138}. Keldysh’s theory provides the theoretical basis for inelastic tunneling electron spectroscopy, single molecule chemistry and motors, for details see, e.g., the text book \cite{139}.

The approach can be generalized to time-dependent situations \cite{140}, or situations where the partitioning of the system into separate leads and a central region must be re-examined \cite{141}. The next level of abstraction can be achieved by formulating the nonequilibrium theory in a field-theory language. This powerful formulation has found a very large number of applications, which are reviewed, e.g. in a recent advanced text-book \cite{142}. The field-theory formulation honors Keldysh by employing many technical terms that commemorate their inventor, e.g., Keldysh rotation, or Keldysh action.

4.3.3 The Rytova-Keldysh potential In 1979 Keldysh considered the Coulomb interaction in thin semiconductor and semimetal films, and proposed a form for the interaction potential between charged particles in such systems \cite{143}. (Work along similar lines was reported earlier by Rytova \cite{144}). A central theme in condensed matter physics in our millennium is concerned with two-dimensional materials, such as graphene, or transition metal dichalcogenides. The Rytova-Keldysh potential forms an important ingredient in the physics of these materials. Recent developments are reviewed, e.g. in \cite{144} where many references to related work can be found.

4.3.4 Stochastic methods applied to the Keldysh contour The idea of treating quantum many-body systems out of equilibrium on the Keldysh time contour has been extended to various other methods. A stochastic sampling method of Feynman diagrams was developed by Werner et al., and is known as diagrammatic Monte Carlo, see \cite{145} and references therein. Diagrammatic Monte Carlo extends earlier equilibrium simulations such as the continuous-time quantum Monte Carlo method for fermions \cite{146} to arbitrary nonequilibrium situations. While it formally can treat strongly coupled systems and is successfully used in condensed matter systems and for cold atoms, it suffers from the dynamic fermion sign problem that strongly limits the simulation duration.

5 The Keldysh school Actually Keldysh’s scientific interests were much broader than one could judge from his list of publications. This is, in part, reflected in the broad range of topics his PhD students worked on, see Sec. 3. One of us (MS) recalls “I first met him in 1969 when I was a third year student of the Ural State University and attended his lectures on exciton condensation and electron–hole droplets at the famous winter school on theoretical physics “Kourovka” near Sverdlovsk (now Ekaterinburg). In 1971 I became his PhD student at the Lebedev Institute in Moscow and, to my surprise, he proposed to me a PhD topic related to the construction of the theory of “liquid semiconductors”—a research field developed previously in the experimental works of the Ioffe–Regel group in Leningrad and still lacking serious theoretical foundation. This reflected Keldysh’s interest in the general theory of electrons in disordered systems, being only developed at that time in the classical works of Neville Mott, Ilya Lifshits and Philip Anderson. In the following years we tried (in fact more or less in vain!) to construct such a theory. Our main idea was to produce a theoretical model of the pseudogap—a concept introduced by Mott on qualitative grounds to explain electronic properties of amorphous and liquid semiconductors. Here we were successful and formulated an exactly solvable model of the pseudogap, based on the summation of a complete series of Feynman diagrams for a simplified 1D model. Actually Keldysh declined co–autorship, so these results appeared under my name only, forming the ground for my future work in many years to follow, leading eventually to the studies of the pseudogap problem in high-$T_C$ superconductors. This model was, in fact, a generalization of a similar diagram summation in Keldysh’s studies of doped semiconductors, which appeared only in his dissertation (1965) and was later used or rediscovered by others. These are only few of many examples of his unpublished results. Most of them he was writing in large notebooks at his home, which some of his students were lucky enough to see.”

The list of Keldysh’s PhD students includes Yu. V. Kopaev, D.I. Khomski, R.R. Guseinov, V.S. Babichenko, B.A. Volkov, M.V. Sadovskii, A.P. Silin, V.E. Bisti, A.V. Vinogradov, S.G. Tikhodeev, E.A. Andryushin, T.A. Onishchenko, N.S. Maslova, and P.I. Arseev, and their year of graduation and research topics are presented in table 11. Many of them became successful scientists themselves. Kopaev, Khomskii, Volkov, Sadovskii, Tikhodeev, Ivanov, Arseev, Maslova, and Gippius later did their habilitation. Gippius, Khomskii, Sadovskii, Tikhodeev, and Vinogradov became professors. Arseev became a corresponding member and Kopaev and Sadovskii full members of the Russian Academy of Sciences.

6 Conclusions There have been a number of obituaries for Keldysh in the U.S. \cite{85} and in Russia \cite{147} that have covered various sides of Keldysh’s scientific work and personality. The 2017 special issue of Physics Uspekhi (issue 11, volume 60) covers in detail Keldysh’s scientific work. There is no need to reproduce this material here. Instead, we have taken the particular angle of view on Keldysh that concentrates on his contributions to nonequilibrium many-body physics, in general, and nonequilibrium Green functions, in particular. Keldysh’s single pa-
Table 1 List of Keldysh’s PhD (above the line) and master students (below) in chronological order, their year of graduation and their scientific topics. See also the list of references at the end of the paper.

| Name             | Graduation | Research topics                                                                 |
|------------------|------------|----------------------------------------------------------------------------------|
| Yu. V. Kopaev    | 1965       | Semimetal-dielectric phase transitions                                           |
| D. I. Khomskii   | 1969       | Systems with strong electronic correlations                                       |
| R. R. Guseinov   | 1971       | Electron-phonon interaction in systems with excitonic instabilities              |
| M. V. Sadovskii  | 1974       | Liquid semiconductors, Pseudogap, Disorder and Fluctuation effects on the 1D Peierls transition |
| A. P. Silin      | 1975       | Condensation of excitons in semiconductors                                        |
| B. A. Volkov     | 1976       | Electronic properties of semiconductors with structural instabilities            |
| A. V. Vinogradov | 1976       | Electronic mechanisms of light absorption of dielectrics in transparency range    |
| E. A. Andryushin | 1977       | Electron-hole liquid in layered semiconductors                                   |
| V. S. Babichenko | 1977       | Electron-hole liquid in strongly anisotropic semiconductors and semimetals       |
| T. A. Onishchenko| 1977       | Electron-hole liquid in strong magnetic field                                    |
| V. E. Bisti      | 1978       | Exciton interactions in semiconductors                                            |
| S. G. Tikhodeev  | 1980       | Interaction of electron-hole liquid in semiconductors with deformations.         |
|                  |            | Nonequilibrium diagram technique for relaxation processes                         |
| A. L. Ivanov     | 1983       | Intensive electromagnetic wave in a direct-gap semiconductor                      |
| I. M. Sokolov    | 1984       | Localization in the Anderson model with correlated site energies, percolation theory |
| P. I. Arseev     | 1986       | Electrodynamics of rough surfaces of metals and semiconductors                    |
| N. S. Maslova    | 1987       | Resonant interaction of light with a system of nonlinear oscillators.             |
|                  |            | Non-equilibrium transport through correlated systems                              |
| N. A. Gippius    | 1988       | Quantum reflection of an exciton from the surface of an electron-hole droplet.    |
|                  |            | Interaction of electromagnetic radiation with semiconductors                      |
| S. S. Fanchenko  | 1975       | Generalized diagram technique of non-equilibrium processes.                      |
|                  |            | The problem of arbitrary initial conditions                                       |

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References

[1] L. Keldysh, Behavior of Non-Metallic Crystals in Strong Electric Fields, Soviet Physics JETP-USSR 6(4), 763–770 (1958).

[2] L. Keldysh, Influence of the Lattice Vibrations of a Crystal on the Production of Electron-Hole Pairs in a Strong Electrical Field, Soviet Physics JETP-USSR 7(4), 665–668 (1958).

[3] L. Keldysh, The Effect of a Strong Electric Field on the Optical Properties of Insulating Crystals, Soviet Physics JETP-USSR 7(4), 788–790 (1958).

[4] B. Vul, E. Zavaritskaia, and L. Keldysh, Impurity Conductivity of Germanium at Low Temperatures, Doklady Akademii Nauk SSSR 135(6), 1361–1363 (1960).

[5] L. Keldysh, Kinetic Theory of Impact Ionization in Semiconductors, Soviet Physics JETP-USSR 10(3), 509–518 (1960).

[6] L. Keldysh, Optical Characteristics of Electrons with a Band Energy Spectrum in a Strong Electric Field, Soviet Physics JETP-USSR 16(2), 471–474 (1963).

[7] L. Keldysh, Effect of Ultrasonics on the Electron Spectrum of Crystals, Soviet Physics-Solid State 4(8), 1658–1659 (1963).

[8] L. Keldysh and Y. Kopaev, The Energy Spectrum of a Degenerate Semiconductor with an Ionic Lattice, Soviet Physics-Solid State 5(5), 1026–1030 (1963).

[9] L. Keldysh, Deep Levels in Semiconductors, Soviet Physics JETP-USSR 18(1), 253–260 (1964).

[10] L. Keldysh and G. Proshko, Infrared Absorption in Highly Doped Germanium, Soviet Physics-Solid State 5(12), 2481–2488 (1964).
[11] V. Bagaev, Y. Berozashvili, B. Vul, E. Zavaritskaya, L. Keldysh, and A. Shotov, Concerning the Energy Level Spectrum of Heavily Doped Gallium Arsenide, Soviet Physics-Solid State 6(5), 1093–1098 (1964).

[12] L. Keldysh, Diagram Technique for Nonequilibrium Processes, Soviet Physics JETP-USSR 20(4), 1018 (1965), [Zh. Eksp. Teor. Fiz. 47, 1515 (1964)].

[13] L. Keldysh, Ionization in Field of a Strong Electromagnetic Wave, Soviet Physics JETP-USSR 20(5), 1307 (1965), [ZhETF 47, 1945–1957 (1964)].

[14] L. Keldysh, Concerning Theory of Impact Ionization in Semiconductors, Soviet Physics JETP-USSR 21(6), 1135 (1965).

[15] L. Keldysh and Y. Kopaev, Possible Instability of Semimetallic State Toward Coulomb Interaction, Soviet Physics Solid State, USSR 6(9), 2219 (1965), [Fiz. Tverd. Tela 6, 2791 (1964)].

[16] L. Keldysh, Superconductivity In Nonmetallic Systems, Soviet Physics Uspekhi-USSR 8(3), 496 (1965).

[17] V. Bagaev, Y. Berozashvili, and L. Keldysh, Electrooptic Effect in GaAs, JETP Letters-USSR 4(9), 246 (1966).

[18] L. Keldysh and T. Tratas, Dynamic Narrowing of Paramagnetic Resonance Lines in a Compensated Semiconductor, Soviet Physics Solid State, USSR 8(1), 64 (1966).

[19] L. Keldysh and A. Kozlov, Collective Properties of Large-Radius Excitons, JETP Letters-USSR 5(7), 190 (1967).

[20] L. Keldysh and A. Kozlov, Collective Properties of Excitons in Semiconductors, Soviet Physics JETP-USSR 27(3), 521 (1968), [Zh. Eksp. Teor. Fiz. 54, 978 (1968)].

[21] V. Bagaev, Y. Berozashvili, and L. a. Keldysh, Anisotropy of Polarized-Light Absorption Produced in GaAs and CdTe Crystals by a Strong Electric Field, JETP Letters-USSR 9(3), 108 (1969).

[22] L. Keldysh and M. Pikhadzade, Conductivity of Semiconductors Under Pinch-Effect Conditions, JETP Letters-USSR 10(6), 169 (1969).

[23] V. Bagaev, T. Galkina, O. Gogolin, and L. Keldysh, Motion of Electron-Hole Drops in Germanium, JETP Letters-USSR 10(7), 195 (1969).

[24] L. Keldysh, O. Konstantinov, and V. Perel, Polarization Effects in Interband Absorption of Light in Semiconductors Subjected to a Strong Electric Field, Soviet Physics Semiconductors-USSR 3(7), 876 (1970).

[25] L. Keldysh, Electron-Hole Drops in Semiconductors, Soviet Physics Uspekhi-USSR 13(2), 292 (1970).

[26] B. Kadomtsev, R. Sagdeev, L. Keldysh, and I. Kobzarov, On A.A. TYAPKIN’s article “Expression of General Properties of Physical Processes in Space-and-Time Metric of Special Theory of Relativity”, Uspekhi Fizicheskikh Nauk 106(4), 660 (1972).

[27] R. Guseinov and L. Keldysh, Nature of Phase-Transitions under Excitonic Instability Conditions of a Crystal Electron Spectrum, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 63(12), 2255–2263 (1972).

[28] L. Keldysh and A. Silin, Electron-Hole Liquids in Semiconductors in Magnetic-Field, FIZIKA TVERDOGO TELA 15(5), 1532–1535 (1973).

[29] L. Keldysh, A. Manenkov, V. Milyaev, and G. Mikhailova, Microwave Breakdown and Exciton Condensation in Germanium, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 66(6), 2178–2190 (1974).

[30] L. Keldysh and S. Tikhodeev, Absorption of Ultrasound by Electron-Hole Drops in a Semiconductor, JETP Letters 21(10), 273–274 (1975).

[31] L. Keldysh and A. Silin, Electron-Hole Fluid in Polar Semiconductors, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 69(3), 1053–1057 (1975).

[32] L. Keldysh, Phonon Wind and Dimensions of Electron-Hole Drops in Semiconductors, JETP Letters 23(2), 86–89 (1976).

[33] L. Keldysh and T. Onishchenko, Electron Liquid in a Superstrong Magnetic-Field, JETP Letters 24(2), 59–62 (1976).

[34] E. Andrushin, V. Babichenko, L. Keldysh, T. Onishchenko, and A. Silin, Electron-Hole Liquid in Strongly Anisotropic Semiconductors and Semimetals, JETP Letters 24(4), 185–189 (1976).

[35] V. Bagaev, L. Keldysh, N. Sibeldin, and V. Tsvetkov, Phonon Wind Drag of Excitons and Electron-Hole Drops, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 70(2), 702–716 (1976).

[36] V. Bagaev, N. Zamkovets, L. Keldysh, N. Sibeldin, and V. Tsvetkov, Kinetics of Exciton Condensation in Germanium, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 70(4), 1500–1521 (1976).

[37] L. Keldysh and S. Tikhodeev, Ultrasonic Absorption by Electron-Hole Drops in Semiconductor, Fizika Tverdogo Tela 19(1), 111–117 (1977).

[38] E. Andrushin, L. Keldysh, and A. Silin, Electron-Hole Liquid and Metal-Dielectric Phase-Transition in Layer Systems, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 73(3), 1163–1173 (1977).

[39] L. Keldysh, Metal-Dielectric Transformation Under Light Action, Vestnik Moskovskovo Universiteta Seria 3 Fizika Astronomia 19(4), 86–90 (1978).

[40] L. Keldysh, Coulomb Interaction in Thin Semiconductor and Semimetal Films, JETP Letters 29(11), 658–661 (1979).

[41] L. Keldysh, Polaritons in Thin Semiconductor-Films, JETP Letters 30(4), 224–227 (1979), [ZHETF Letters 29, 658 (1979)].

[42] V. Bagaev, M. Bonchosmolovskii, T. Galkina, L. Keldysh, and A. Poyarkov, Entrainment of Electron-Hole Drops by a Strain Pulse Produced as a Result of Laser Irradiation of Germanium, JETP Letters 32(5), 332–335 (1980).

[43] E. Andrushyn, L. Keldysh, V. Sanina, and A. Silin, Electron-Hole Liquid in Thin Semiconductor-Films, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 79(4), 1509–1517 (1980).

[44] L. Keldysh and A. Kechek, On the Dielectric-Constant of The Non-Polar Fluid, Doklady Akademii Nauk SSSR 259(3), 575–578 (1981).

[45] A. Ivanov and L. Keldysh, The Propagation of Powerful Electromagnetic-Waves in Semiconductors under the Resonant Excitation of Excitons, Doklady Akademii Nauk SSSR 264(6), 1363–1366 (1982).

[46] A. Ivanov and L. Keldysh, Modification of the Polariton and Phonon-Spectra of a Semiconductor in the Presence of...
of an Intense Electromagnetic-Wave, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 54(1), 404–421 (1983).

[47] N. Gippius, V. Zavaritskaya, L. Keldysh, V. Milyaev, and S. Tikhodeev, Quantum Nature Of the Reflection of an Exciton from the Surface of an Electron-Hole Drop, JETP Letters 40(10), 1235–1238 (1984).

[48] P. Elyutin, L. Keldysh, and A. Keche, The Resonance Dielectric Permittivity of Nonpolar Liquids, Optika i Spektroskopiya 57(2), 282–287 (1984).

[49] L. Keldysh and S. Tikhodeev, High-Intensity Polariton Wave Near the Stimulated Scattering Threshold, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 90(5), 1852–1870 (1986).

[50] L. Keldysh and S. Tikhodeev, Nonstationary Mandelstam-Brillouin Scattering of an Intense Polariton Wave, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 91(1), 78–85 (1986).

[51] N. Gippius, L. Keldysh, and S. Tikhodeev, Mandelstam-Brillouin Scattering of an Incoherent Polariton Wave, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 91(6), 2263–2275 (1986).

[52] L. Keldysh, Excitons and Polaritons in Semiconductor Insulator Quantum Wells and Superlattices, Superlattices and Microstructures 4(4-5), 637–642 (1988).

[53] A. Ivanov, L. Keldysh, and V. Panashchenko, Low-Threshold Exciton-Biexciton Optical Stark-Effect in Direct-Gap Semiconductors, Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki 99(2), 641–658 (1991).

[54] A. Ivanov, L. Keldysh, and V. Panashchenko, Nonlinear Optical-Response of Interacting Excitons, Institute of Physics Conference Series (126), 431–436 (1992).

[55] L. Keldysh, Excitonic Molecules in Nonlinear Optical-Response, Physica Status Solidi B 173(1), 119–128 (1992).

[56] L. Keldysh, Coherent Excitonic Molecules, Solid State Communications 84(1-2), 37–43 (1992).

[57] N. Gippius, T. Ishihara, L. Keldysh, E. Muljarov, and S. Tikhodeev, Dielectrically Confined Excitons and Polaritons in Natural Superlattices - Perovskite Lead Iodide Semiconductors, Journal de Physique IV 3(C5), 437–440 (1993), 3rd International Conference on Optics of Excitons in Confined Systems, Univ Montpellier II, Montpellier, France, Aug 30-Sep 02, 1993.

[58] N. Gippius, S. Tikhodeev, and L. Keldysh, Polaritons in Semiconductor-Insulator Superlattices with Nonlocal Excitonic Response, Superlattices and Microstructures 15(4), 479–482 (1994).

[59] L. Keldysh, Correlations in the Coherent Transient Electron-Hole System, Physica Status Solidi B 188(1), 11–27 (1995), 4th International Workshop on Nonlinear Optics and Excitation Kinetics in Semiconductors (NOEKS IV), Gosen, Germany, Nov 06-10, 1994.

[60] A. Ivanov, H. Wang, J. Shah, T. Damen, L. Keldysh, H. Haug, and L. Pfeiffer, Coherent transient in photoluminescence of excitonic molecules in GaAs quantum wells, Physical Review B 56(7), 3941–3951 (1997).

[61] L. Keldysh, Excitons in semiconductor-dielectric nanostuctures, Physica Status Solidi A 164(1), 3–12 (1997), 5th International Meeting on Optics of Excitons in Constrained Systems (OECS 5), Göttingen, Germany, Aug 10-14, 1997.

[62] A. Ivanov, H. Haug, and L. Keldysh, Optics of excitonic molecules in semiconductors and semiconductor microstructures, Physics Reports 296(5-6), 237–336 (1998).

[63] Q. Vu, H. Hang, and L. Keldysh, Dynamics of the electron-hole correlation in femtosecond pulse excited semiconductors, Solid State Communications 115(2), 63–65 (2000).

[64] L. Keldysh, Biexcitons at high densities, Pysica Status Solidi B 234(1), 17–22 (2002).

[65] F. Klappenberger, K. Renk, S. Summer, L. Keldysh, B. Rieder, and W. Wegscheider, Electric-field-induced reversible avalanche breakdown in a GaAs microcrystal due to cross band gap impact ionization, Applied Physics Letters 83(4), 704–706 (2003).

[66] L. Keldysh, Real-Time Nonequilibrium Green’s Functions, in: Progress in Nonequilibrium Green’s functions II, edited by M. Bonitz and D. Semkat, (World Scientific Publ., Singapore, 2003), pp. 4–17, [reprinted as supplemental material].

[67] J. Reithmaier, G. Sek, A. Loffler, C. Hofmann, S. Kuhn, S. Reitzenstein, L. Keldysh, V. Kulakovskii, T. Reinecke, and A. Forchel, Strong coupling in a single quantum dot-semiconductor microcavity system, Nature 432(7014), 197–200 (2004).

[68] N. Gippius, S. Tikhodeev, L. Keldysh, and V. Kulakovskii, Hard excitation of stimulated polariton-polariton scattering in semiconductor microcavities, Physics Uspekhi 48(3), 306–312 (2005).

[69] Y. Osipov, V. Sadovnichii, V. Kozlov, O. Krokhin, N. Zefirov, E. Velikhov, G. Dobrovoll’skii, L. Keldysh, S. Nikol’skii, Y. Tret’yakov, K. Frolov, V. Khain, E. Chazov, V. Yanin, V. Kabanov, A. Solzhentisyn, L. Faddeev, A. Andreev, G. Chernyi, V. Lunin, G. Dobrovoll’skii, D. Pushcharovskii, V. Stepin, A. Derevyanko, A. Kudelin, R. Nigmatulin, T. Ozerman, N. Dikanskii, N. Plate, V. Kostyk, and V. Ursusov, Joint scientific session of the General Meeting of the Russian Academy of Sciences and the Academic Council of Moscow State University named after M.V. Lomonosov, dedicated to the 250th anniversary of Moscow State University, Herald of the Russian Academy of Sciences 75(3), 214–270 (2005).

[70] G. Sek, C. Hofmann, J. Reithmaier, A. Loffler, S. Reitzenstein, M. Kamp, L. Keldysh, V. Kulakovskii, T. Reinecke, and A. Forchel, Investigation of strong coupling between single quantum dot excitons and single photons in pilar microcavities, Physica E 32(1-2), 471–475 (2006), 12th International Conference on Modulated Semiconductor Structures (MSS12), Albuquerque, NM, JUL 10-15, 2005.

[71] S. Reitzenstein, A. Loffler, C. Hofmann, A. Kubanek, M. Kamp, J. Reithmaier, A. Forchel, V. Kulakovskii, L. Keldysh, I. Ponomarev, and T. Reinecke, Coherent photonic coupling of semiconductor quantum dots, Optics Letters 31(11), 1738–1740 (2006).

[72] S. Reitzenstein, C. Hofmann, A. Loffler, A. Kubanek, J.P. Reithmaier, M. Kamp, V.D. Kulakovskii, L.V. Keldysh, T.L. Reinecke, and A. Forchel. Strong and weak
coupling of single quantum dot excitons in pillar microcavities, Physica Status Solidi B 243(10), 2224–2228 (2006), 8th International Workshop on Nonlinear Optics and Excitation Kinetics In Semiconductors (NOEKS 8), Münster, Germany, FEB-20-24, 2006.

[73] L. V. Keldysh, V. D. Kulakovskii, S. Reitzenstein, M. N. Makonin, and A. Forchel, Interference effects in the emission spectra of quantum dots in high-quality cavities, JETP Letters 84(9), 494–499 (2006).

[74] S. Reitzenstein, A. Loffler, A. Kubanek, C. Hofmann, M. Kamp, J. P. Reithmaier, A. Forchel, V. D. Kulakovskii, L. V. Keldysh, I. V. Ponomarev, and T. L. Reinecke, Coherent photonic coupling of semiconductor quantum dots (vol 31, pg 1738, 2006), Optics Letters 31(23), 3507 (2006).

[75] L. V. Keldysh, Dynamic Tunneling, Herald of the Russian Academy of Sciences 86(6), 413–425 (2016).

[76] L. V. Keldysh, Coherent states of excitons, Physics Uspekhi 60(11), 1180–1186 (2017).

[77] L. V. Keldysh, Multiphoton ionization by a very short pulse, Physics Uspekhi 60(11), 1187–1193 (2017).

[78] A. Aleksandrov, Z. Alferov, N. Basov, E. Velikhov, A. Gonchar, A. Dynkin, L. Keldysh, D. Knoorre, V. Kotelnikov, G. Mesyats, Y. Osipov, V. Pokrovskii, B. Saltykov, V. Subbotin, L. Faddeev, E. Chelyshev, and V. Shorin, State Research Centers (Discussion in The Russian-Academy-of-Sciences), Vestnik Rossiskoi Akademii Nauk(12), 14–29 (1992).

[79] L. Keldysh, Russian Science at The Approaching Market, Vestnik Rossiskoi Akademii Nauk(3), 45–52 (1992).

[80] A. Alferov, V. Ginzburg, V. Goldanskii, L. Keldysh, V. Maslov, A. Spirin, and V. Kellisborn, Urgent Appeal for Help, Chemical & Engineering News 70(7), 2 (1992).

[81] A. Gonchar, A. Spirin, Y. Osipov, D. Knoppe, N. Shilo, L. Faddeev, V. Sadovnichii, Z. Alferov, E. Velikhov, V. Subbotin, V. Martynov, V. Kudryavtsvev, I. Makarov, E. Chelyshev, A. Prokhorov, M. Strikovich, V. Orel, V. Sokolov, P. Simonov, L. Keldysh, G. Semin, A. Egorov, B. Saltykov, N. Basov, and L. Naverov, What doctrine of science advancement is needed by Russia? Discussion in the RAS Presidium, Vestnik Rossiskoi Akademii Nauk 66(1), 16–25 (1996).

[82] Z. Alferov, Y. Osipov, A. Spirin, V. Subbotin, E. Velikhov, N. Laverov, G. Golitsyn, A. Gonchar, I. Makarov, A. Prokhorov, V. Sobolev, and L. Keldysh, The Ioffe Physico-Technical Institute in the new economic conditions - Discussion in the RAS Presidium, Vestnik Rossiskoi Akademii Nauk 66(6), 491–498 (1996).

[83] V. Ginzburg and L. Keldysh, The age qualification in elections to the Academy of Sciences cannot be tolerated, Vestnik Rossiskoi Akademii Nauk 67(4), 321–322 (1997).

[84] A. Boyarchuk and L. Keldysh, From a physics laboratory to the General Physics and Astronomy Division, Uspekhi Fizicheskikh Nauk 169(12), 1289–1298 (1999).

[85] F. Capasso, P. Corkum, O. Kocharovskyakaya, L. Pitaevskii, and M. Sadovskii, Leonid Keldysh, Physics Today 70, 75 (2017), shortened version of the present text.

[86] W. Franz, Einfluss eines elektrischen Feldes auf eine optische Absorptionskante, Z. Naturforsch. Teil A 13, 484 (1958).

[87] S. V. Popruzenko, Keldysh theory of strong field ionization: history, applications, difficulties and perspectives, J. Phys. B: At. Mol. Opt. Phys. 47, 204001 (2014).

[88] M. Bonitz, Quantum Kinetic Theory, 2 edition, Teubner-Texte zur Physik (Springer, 2016).

[89] P. C. Martin and J. Schwinger, Theory of many-particle systems i, Phys. Rev. 115(Sept), 1342–1373 (1959).

[90] L. Kadanoff and G. Baym, Quantum Statistical Mechanics (Benjamin, New York, 1962).

[91] P. Martin, Quantum kinetic equations, in: Progress in Nonequilibrium Green’s functions, edited by M. Bonitz, (World Scientific Publ., Singapore, 2000), pp. 2–16.

[92] G. Baym, Conservation laws and the quantum theory of transport: The early days, in: Progress in Nonequilibrium Green’s functions, edited by M. Bonitz, (World Scientific Publ., Singapore, 2000), pp. 17–32.

[93] A. Abrikosov, Story about the temperature technique, in: Progress in Nonequilibrium Green’s functions II, edited by M. Bonitz and D. Semkat, (World Scientific Publ., Singapore, 2003), pp. 2–3.

[94] Supplementary material, include URL.

[95] P. Danielewicz, Quantum theory of nonequilibrium processes II. Application to nuclear collisions, Annals of Physics 152(2), 305 – 326 (1984).

[96] M. Bonitz and A. Filinov, Progress in Nonequilibrium Green’s Functions III, Journal of Physics: Conference Series 35(1) (2006).

[97] W. Schäfer and M. Wegener, Semiconductor Optics and Transport Phenomena (Springer, 2002).

[98] T. Bornath, W. Kraeft, R. Redmer, G. Röpke, M. Schlanges, W. Ebeling, and M. Bonitz, A tribute to Dietrich Kremp, Contributions to Plasma Physics 57(10), 434–440 (2017).

[99] D. Kremp, M. Schlanges, and W. Kraeft, Quantum Statistics of Nonideal Plasmas (Springer, 2005).

[100] H. Haug and A. P. Jauho, Quantum Kinetics in Transport and Optics of Semiconductors (Springer, 2008).

[101] M. Bonitz and D. Semkat, Progress in Nonequilibrium Green’s Functions II, Progress in Nonequilibrium Green’s Functions (World Scientific, 2003).

[102] M. Bonitz and K. Balzer, Progress in Nonequilibrium Green’s Functions IV, Journal of Physics: Conference Series 220(1), 011001 (2010).

[103] R. van Leeuwen, R. Touvinen, and M. Bonitz, Progress in Nonequilibrium Green’s Functions V (PNGF V), Journal of Physics: Conference Series 427(1), 011001 (2013).

[104] C. Verdozzi, A. Wacker, C. O. Almbladh, and M. Bonitz, Nonequilibrium Green’s functions, edited by M. Bonitz, (World Scientific Publ., Singapore, 2000), pp. 2–16.

[105] M. Bonitz and K. Balzer, Progress in Nonequilibrium Green’s Functions IV, Journal of Physics: Conference Series 220(1), 011001 (2010).

[106] K. Balzer, M. Bonitz, R. van Leeuwen, A. Stan, and N. E. Dahlen, Nonequilibrium Green’s function approach to strongly correlated few-electron quantum dots, Phys. Rev. B 79(Jun), 245306 (2009).
[142] A. Kamenev, Field Theory of Non-Equilibrium Systems (Cambridge University Press, 2011).
[143] N. S. Rytova, Coulomb interaction of electrons in a thin film, Doklady Akademii Nauk SSSR 163, 1118 (1965).
[144] R. Y. Kezerashvili and S. M. Tsiklauri, Trion and biexciton in monolayer transition metal dichalcogenides, Few-Body Systems 58(1), 18 (2016).
[145] P. Werner, T. Oka, and A. J. Millis, Diagrammatic Monte Carlo simulation of nonequilibrium systems, Phys. Rev. B 79(Jan), 035320 (2009).
[146] A. N. Rubtsov, V. V. Savkin, and A. I. Lichtenstein, Continuous-time quantum Monte Carlo method for fermions, Phys. Rev. B 72(Jul), 035122 (2005).
[147] Physics Uspekhi 60 (11), 1065 (2017).