Contributions of Yuri L. Klimontovich to the Kinetic Theory of Nonideal Plasmas

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We give a short summary of live and work of Yuri L. Klimontovich (1924-2002), in particular we discuss his work on nonideal plasma physics.

> *Finally we arrived at the end of our long way. No doubt, not everything*
> *on this long pathwas sufficiently smooth.*
> Yuri L. Klimontovich, in the conclusions to his book "Statistical Physics" (1982)

1 On the biography of YLK

YLK was born on September 28 1924 in Moscow. His mother, Natalia Vladimirovna Vladykina, was from the famous russian noble family Vladykin which is of tataric origin and took service under Ivan the Terrible. At that time they obtained very large land property and became wealthy (what expresses the meaning of the family name). His father also came from a noble family, in second generation. He was arrested under Stalin's terror regime in 1931 and killed after 2 weeks (only 62 years later the family received an official information). Since his mother died soon after, Yuri and his 2 brothers lived with the family of an aunt under very poor conditions. To support the family, Yuri carried luggage at railway stations. He fell ill on tuberculosis and survived a very difficult operation. For this reason he did not serve in the army and studied for a short time at an Engineering institute (college). After the war, in 1946, Yuri began to study physics at Moscow State Lomonosov University (MGU). The advisor of his diploma (master) thesis on "radiative friction" was Prof. V.S. Fursov. The very engaged young man wanted to become an "aspirant" (graduate student) and write a dissertation. However, this was refused by the authorities since he was considered the son of a "repressirovan" (repressed) father. Shortly after the refusal of "aspirantura" and of emplyment at the Academy of sciences as well, just by a lucky chance, Yuri met Prof. Nikolai N. Bogoliubov near the Academy who asked him about his plans. Having a very high opinion about Yuri, Bogoliubov took him personally as a PhD student, ignoring the official decision. In 1951 Yuri defended his dissertation. He knew very well that without the support of Fursov (who later served many years as the dean of the Department and Bogoliubov (who later held high positions in the Academy) he never would have had a chance to make a scientific carrier. He always expressed highest opinions about his advisors.

Starting physics with some problems given by his advisors, YLK went on to develop quite independently a new theory of plasmas based on his new method called "second quantization in phase space". Among his co-authors of this period were Silin (work on excitation spectra), and Ebeling (hydrodynamic approximation). Since 1952 YLK had the position of a docent at the Aviation Technology Institute and, since 1955, at Moscow State University at the Chair of Prof. S.P. Strelkov. At that time, there was a remarkable group of young colleagues, including R. Stratonovich, V. Schmalgausen, Yu. Romanovsky, P. Landa, who all have made important contributions to

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physics. Supported by Bogoliubov, YLK defended his second dissertation at the Steklov Institute and got the position of a full professor at his University in 1965.

Alltogether, YLK tought 40 years at the MGU. He was an excellent teacher who never used a manuscript. First as a docent, later as a professor, he tought Statistical Physics at the Physics Department, the Department of Mechanics and Mathematics and the Department of Higher Qualification. YLK educated numerous russian students and postdocs among them: Anishenko, Astashkina, Belyi, Chechkin, Chetverikov, Emelyanov, Kucharenko, Slinko, ... Among his foreign students and postdocs were: Bonitz, Bornath, Ebeling, Engel-Herbert, Handrich, Kraeft, Kremp, Leven, Schlanges, Ulbricht, ...

The work of YLK was honoured by many institutions. He was a visiting professor at the Universities of Berlin, Bruxelles, Como, Greifswald, Paris, Rome and Rostock. He was awarded
the Medal of honour (Ehrennadel) of Rostock University (1986),
the title "Doctor honoris causa" from Rostock University (1990),
the State Prize of Russia (1991),
the Prize of the Humboldt Foundation Germany (1994),
repeated Soros professorships (1995-1998),
the Kapitsa gold medal of the Russian Academy of Natural Science (1997)

On November 27 2002, Yuri L. Klimontovich passed away, short time after a cancer operation. He left a wife: Svetlana O. Mayevskaya, and two children, Nikolai and Katya, and a grandson, Wanya.

2   Early work and first book on nonequilibrium plasmas 1950-1964

Only in his diploma thesis and in his dissertation some influence of his advisors is to be seen. Later YLK developed quite independently a completely new theory of plasmas. The basic new idea (1957) is the introduction of a random function constructed from all dynamical particle trajectories, $\mathbf{r}_i(t), \mathbf{p}_i(t)$

$$N(\mathbf{r}, \mathbf{p}, t) = \sum_{i=1}^{N} \delta\left[\mathbf{r} - \mathbf{r}_i(t)\right] \delta\left[\mathbf{p} - \mathbf{p}_i(t)\right].$$

This one-particle function obeys the classical Vlasov equation which is closed, (we denote $x \equiv (\mathbf{r}, \mathbf{p})$),

$$\left(\frac{\partial}{\partial t} + \mathbf{v}\frac{\partial}{\partial \mathbf{r}} - \frac{\partial}{\partial \mathbf{r}}U_{\text{eff}}(\mathbf{r}, \mathbf{p}, t)\frac{\partial}{\partial \mathbf{p}}\right) N(x, t) = 0,$$

$$U_{\text{eff}}(\mathbf{r}, \mathbf{p}, t) = U_{\text{ext}}(\mathbf{r}, t) + \int dx' \Phi(|\mathbf{r} - \mathbf{r}'|) N(x', t),$$

in full analogy to the field operators $\psi, \psi^\dagger$ in quantum field theory. Therefore, YLK called his method "second quantization in phase space", today it is simply referred to as the "Klimontovich method". It yields, in particular:

1. **Statistical quantities**: Performing a statistical average leads to the one-particle distribution, $\bar{N}(x, t) = nf_1(x, t)$, and immediately to the infinite Bogolyubov (BBGKY) hierarchy, because $\overline{N(x, t) \cdot N(x', t)} = n\delta(x - x')f_1(x, t) + n^2 f_2(x, x', t)$, and all correlation functions, $g_2, g_3, \ldots$.

2. **Collision integrals**: Using this method, he could explicitly compute collision integrals for nonideal gases and plasmas, including the Landau and Lenard-Balescu integral and far-reaching generalizations.

3. **Fluctuations**: Subtraction of averages yields fluctuations of particles, $\delta N(x, t) = N(x, t) - nf_1(x, t)$, and fields, $\delta\mathbf{E}$, and a complete nonequilibrium theory of fluctuations.

4. **Spectral functions**: From analyzing the correlators $\delta N \delta N$ and $\delta\mathbf{E}\delta\mathbf{E}$ follow directly the (two-time!) spectral functions of particles and fields.

YLK could show that this elegant method works also in the quantum case and can be straightforwardly generalized to relativistic systems. It became the basis for all his subsequent work in a large variety of fields. Its first extended presentation was given in his first monograph *Statistical Theory of Nonequilibrium Processes* in 1964.

Among other early work we mention his papers on
– Electromagnetic fluctuations in plasmas, dielectric function and dispersion relation in quantum plasmas published 1952 together with V.P. Silin (2 years before Lindhard).
– Quantum kinetic equations for time and energy (essentially two-time)-dependent distribution functions (1956).
– Coupled kinetic equations for charged particles and plasmons 1959 (independently of Bohm and Pines), influence of turbulent excitations and nonlinear waves on the collision integral .
– Hydrodynamic approximations (with W. Ebeling).
– His review on nonequilibrium dynamics in plasmas (with Silin 1960) had a profound influence on future developments in many-body physics in general and, in particular, on L.V. Keldysh's foundation of nonequilibrium Green's functions theory [E].

3 Nonideality effects and electromagnetic processes 1965-1980

YLK soon realized that conventional kinetic equations yield only equilibrium results of *ideal* gases and plasmas and proceeded to derive generalized kinetic equations. In particular
– he derived a non-Markovian Landau equation,
– developed the concept of retardation expansion,
– demonstrated that the first order retardation and nonlocality terms assure total energy conservation,
– derived, from these kinetic equations, hydrodynamic and gasdynamic equations of nonideal system,
– microscopically derived nonideality corrections to thermodynamic (pressure, energy etc.) and transport quantities (conductivity, optical absorption, spectral line shapes etc.),
– he derived collision integrals for kinetic equations in the presence of electromagnetic fields.
– he derived kinetic equations for atoms in electromagnetic fields and for partially ionized plasmas.
– he systematically developed the theory of fluctuations in gases, plasmas and in active systems, including nonlinear oscillating systems with feedback and lasers.

These results and many others form the basis of two monographs: *Kinetic Theory of nonideal gases and nonideal plasmas* (1975) and *Kinetic theory of electromagnetic processes* (1980).

Characteristic for his publications and these books is that he avoided extensive dealing with formal mathematical aspects – his main focus were always practical applications, calculation of directly measurable quantities. Since the end of the seventies Klimontovich visited many times his former students and colleagues in East Germany in particular at Rostock University. In May 1979 in Lähnwitz, a nice resort place near Güstrow and Rostock, a workshop devoted to transport properties of dense plamas took place. This workshop was a forerunner of the series of PNP-workshops. The first "counted PNP-workshop" took place in 1980 in another resort place Matzlow-Garwitz. YLK participated also in many of the subsequent workshops in Wustrow 1980,1988, Biesenthal 1984, Greifswald 1986, Berlin/Gosen 1991, Rostock/Markgrafenheide 1993, Binz 1995, Rostock 1998, Greifswald 2000.
In 1984 appeared a book which we consider (by definition) as the first PNP-proceedings. YLK contributed two articles to this book (with the coauthors Ebeling/Kraeft/Kremp/Röpke and Schlanges).

4 Principles of statistical physics and of open systems 1982-1999

After a large number of original publications on a variety of different fields, numerous review articles and 3 monographs addressed to specialists, YLK decided to gather his results and experience into a text book which would be understandable for undergraduate students. And in fact, he succeeded.

The **text book "Statistical Physics"** is unique in the field, since it is completely based on a nonequilibrium approach. So the whole Statistical Physics is developed in an intrinsically consistent way. YLK succeeds in presenting all subjects as part of one common area of physics (which is in striking contrast to many standard text books), many relations between "usually" independent fields and applications are becoming evident by this approach.

Last but not least Klimontovich devoted many effoprts to the development of the theory of quantum plasmas, radiation and quantum open systems. The interaction of radiation with quantum systems and, in particular, with quantum plasmas was a central topic of Yuri's work. He started with this subject in his diploma thesis which was

published soon with Fursov in his first paper: *The influence of the interaction between molecules on the radiative friction in the classical theory of the dispersion of light* (1949). Finally he devoted his last book to the quantum theory including radiation. Among the fundamental problems he was able to solve are:

- derivation of nonideal quantum kinetic equations,

- formulation of a new fluctuation dissipation theorem for dissipative systems,

- fluctuation dissipation relations for atoms in radiation fields.

- new approaches to superfluidity and superconductivity.

5 Summary

Klimontovich's C.V. is by no means an average one. Despite very difficult conditions, he was able to create a great scientific work which led several people call him a "Boltzmann of the 20th century". His most remarkable achievements in the field of plasma theory are:

- derivation of kinetic equations for charged particles and fields, including partial ionization, interactions with plasmons, nonlinear waves, turbulence etc.,

- microscopic theory of fluctuations and its application to kinetic and hydrodynamic theory,

- quantum kinetic equations and relativistic generalizations,

- most importantly: the microscopic phase space density method which will remain one of the most powerful and consistent approaches in many-body physics.

6 Articles dedicated to Klimontovich

[A] W. Ebeling, Yu.M. Romanovsky: *On the 75th birthday of Yuri L. Klimontovich* , Contr. Plasma Physics **39**, 285-286 (1999)

[B] Contr. Plasma Physics: **39** No. 4 (1999): Special issue with articles dedicated to Yu.L. Klimontovich's 75th birthday

[C] V.S. Anishchenko: *Yu.L. Klimontovich*, Izv. Vusov – Prikladnaya Nelineynaya Dinamika **10** 147-149 (2003) (in Russian)

[D] G.I. Gdalevich: *Pamyati Yurija Lvovicha Klimontovicha*, Nauchnaya Gazeta Nauka i Technologia Rossii, March (2003)

[E] M. Bonitz: *In memoriam Yuri Klimontovich*, p. vii in: *Progress in Nonequilibrium Green's Functions II*, M. Bonitz and Dirk Semkat (eds.), World Scientific Publ., Singapore 2003