Analysis of Theories of Fully Ionized Space Plasma

Alexandr Chertkov
Institute of Physics, Physical Faculty, Sankt-Petersburg State University, 198904 Sankt-Petersburg, Petrodvorets, Russia, A.Chertkov@pobox.spbu.ru

Abstract.
The physical sense of main ideas, presented now in plasma physics, is discussed. An attempt to clarify the true images of objects, really used in plasma physics during the processes of calculations, is made. The construct "Coulomb collision" with the properties of Boltzmann collisions plays the key negative role in physics of fully ionized plasma. A new concept of fully ionized space plasma is considered.

Keywords: space plasma physics, stochastization in plasma,

1. Introduction.

Physics of the solar wind and internal Sun meets with great difficulties, connected with impossibility to describe the observed properties of fully ionized space plasma in framework of a uniform internally consistent theory (Alfvén and Arrhenius, 1976; Alfvén, 1981; Chertkov, 1985). The theory of fully ionized plasma is not able to give explanations for results of laboratory experiments in the field of controlled fusion (Gott and Yurchenko, 1996). The aim of the paper is to show that all the difficulties are not accidental ones. They stem from the profound errors in the ordinary way of theoretical calculations, replacing the parallel interaction of charged plasma particles by series of so-called consequent "Coulomb collisions" with very rapid loss of information about previous state of plasma. The most part of errors is connected with simplified methods of formulating the problems and setting up the boundary conditions for space and laboratory plasma. An analysis of logical chains and identification problems arising during the process of comparison of initially declared items of plasma models with the true items of the models and with real objects in space plasma is presented here.

2. Difficulties in Space Plasma Theory.

2.1. Unsolved Problems in Space and Solar Physics.

A concise and not complete list of unsolved till now problems in space and solar physics is the following.

(1) How can the Sun, having the surface temperature of about $6,000$ K, heat the corona up to about $2,000,000$ K (Zirin, 1966; Gibson, 1973)? (2) How can the Sun accelerate the solar wind to supersonic and super-Alfvenic velocity (Brandt, 1970)? (3) How does a moving solar wind proton receive energy more than twenty times higher than its initial kinetic energy (Parker, 1963)? (4) Why does not the solar wind get cool even at distances of $1-10$ AU (Chertkov, 1985)? (5) Why can the solar wind be perfectly described by isotropic hydrodynamics, when the mean free path due to so called "Coulomb collisions" in plasma is more than 1AU? When the mean free path is provided by the Larmor precession in magnetic field (Baranov and Krasnobayev, 1977), one can receive only anisotropic MHD description of plasma (Chertkov, 1985). (6) Why the apparent thermal conductivity for electrons is much higher than that for protons (Hundhausen, 1972)? When the mean free path in plasma had been produced by the above mentioned Larmor precession, this ratio would have been the opposite one (Chertkov, 1985). (7) Why does the theoretical relaxation time for ordinary space objects similar to coronal loops or helmets exceed 10^{11} years, contrasting with the observed relaxation time about hours (Chertkov, 1998b; Nakariakov et al., 1999)? (8) Why does not the measured solar neutrino flux coincide with the calculated one (Bahcall, 1989)?

An analysis showed that all these problems are interrelated and connected with drawbacks of plasma theory for fully ionized space plasma (Chertkov, 1985; Chertkov, 1997a; Chertkov, 1998a).

2.2. History of Plasma Physics.

The history of physics of the fully ionized plasma had two bifurcation points: the one in 1937 and the other in 1946. Both were connected with the preference of simplified calculation methods over deep analysis of real plasma properties. Then the theory confronted with the results of controlled fusion experiments, and till now it is not adequate to experimental and empirical data. L.D.Landau suggested in 1937 a model of fully ionized plasma with so called "Coulomb collisions" (Landau, 1937). They replace the complicated simultaneous interaction of many charged particles by a series of artificial consequent collisions with small change of impulses. The main feature of the model, which is very important for our investigation, is a very rapid loss of information about previous state of plasma, implicitly introduced in calculations with the use of a hypothesis equivalent to Stosszahlansatz by L.Boltzmann. It is the well known "integral of collisions" in the form by Landau. A.A.Vlasov demonstrated in 1938, that the integral diverges (Vlasov, 1938). Vlasov suggested the equation with a self-consistent field. It is a model with parallel interaction of particles, keeping information about a previous state of plasma. The fundamental difference between the method of descriptions of charged particle systems, suggested by A.A.Vlasov, and the method by L.Boltzmann is the following – citation from (Vlasov, 1950): "1. A denial of principle of point-like localization of particles in sense of classical mechanics. 2. The behavior of every particle of the system is described with the use of f-function, stretched in the phase space. 3. Not only close but arbitrarily distant interactions of every particle with all the collective of particles are considered. Mathematical apparatus of the method assumes two interpretations of the sense of f-function: it can evaluate a statistical dispersion in a position of the point-like particle, or it can be a generalization of the notion of particle by itself, giving the image of the particle, stretched in phase space of six dimensions."

A.A.Vlasov developed his theory on the base of the second interpretation (Vlasov,1938;1945;1950;1966;1978). But almost all the other works in the field of physics of fully ionized plasma use (or, at least, imply) the first interpretation (Landau and Livshits, 1979; Galeev and Sudan, 1984; Klimontovich, 1997).

The work (Ginzburg et.al., 1946) appeared under the title "About Inconsistency of Works by A.A.Vlasov on General Theory of Plasma and Physics of Solid Body" and declared, that all the results, obtained in criticized works, were erroneous. The base of the statement was the fact, that A.A.Vlasov, in the process of solution of his equation, calculated a singular integral in sense of principal value. In 1946 L.D.Landau formulated a new way of calculation for these singular integrals - a special rule to go round the integration path. It allowed him to obtain a "collisionless damping" of waves in fully ionized plasma, solving Vlasov equation, which keeps entropy (Landau, 1946).

In 1946 BBGKY chain, named by the names of all the authors, (Bogolyubov-Born-Green-Kirkwood-Yvon) was suggested (Bogolyubov, 1946; Born and Green, 1946; Kirkwood, 1946; Yvon, 1935). It is a chain of connected equations for the series of linked partial distribution functions, describing stochastic behavior of an ensemble of interacting particles, starting from Liuville equation for the ensemble. Liuville equation is equivalent to the full system of exact dynamical equations (Newton equations) for all the particles. BBGKY chain is the main instrument of statistical physics now (Liboff, 1969; Koga, 1970; Cercignani, 1975). However, N.N.Bogolyubov was the first, who demonstrated the divergence of the chain for fully ionized plasma (Bogolyubov, 1946). Vlasov equation was adopted as the first approximation for collisionless plasma in framework of BBGKY chain, and a combination of Vlasov equation with integral of collisions by Landau occurred the second approximation

(Clemmow and Dougherty, 1969; Akhiezer et al., 1974). But these two approaches – by Landau and by Vlasov – contain direct contradictions and it is not a solved problem (Koga, 1970; Chertkov, 1998a). All the statistical methods, applied in present day plasma physics, contain divergence (Balescu, 1975; Krommes, 1984; Yerofeyev and Malkin, 1989). The divergence is removed with additional hypotheses, ordinarily with the hypothesis about Debye screening (Debye and Hückel, 1923) or weakening of correlations (Klimontovich, 1982). But, as it was shown in (Koga, 1970; Schmidt, 1991), different parts of the theory are not coordinated; regions of validity of these parts do not coincide; comparison with experiments can be made very conventionally.

Let us discuss the physical sense of main ideas, presented now in plasma physics. It will be connected with the clarifying of true images of objects, really used in plasma physics during the processes of calculations.

2.3. "Coulomb Collisions" in Collisionless Plasma.

The image of the "Coulomb collisions" is the fundamental of present day plasma theory (Shkarofsky et al., 1966; Krall and Trivelpiece, 1973). It stems from the unnecessary analogy of Boltzmann gas collisions and particle interaction through a self-consistent field in fully ionized plasma. This analogy is incorrect and lead to the heavy errors. It replace the parallel interaction of plasma particles with no loss of memory about its prehistory by a series of consequent "collisions" with very rapid loss of memory. This rapid loss take place only for simply not ionized gases (Kravtsov, 1989; Chertkov, 1997a). The difference in evaluating of plasma electrical conductivity in framework of consequent "collision" concept and in framework of empirical estimations can amount fourteen orders in magnitude for the solar wind plasma (Chertkov, 1985; Chertkov, 1992). What is the cause of contradictions?

The formula for cross-section of Coulomb interaction between two charged particles was obtained by E.Rutherford for the case of bombarding of the foil target by a beam of α-particles (Rutherford, 1911). The direction of the beam was approximately normal to the plane of the foil target; the foil was very thin; the density of the beam was very small. All these conditions created the possibility to treat the result of bombarding as the sum of consequent pair interactions between a certain α-particle and a certain nucleus of an atom of the target. Different results of interaction (different angles of deflection) were explained by introducing of a collision parameter, which is so small, that cannot be controlled. The collision parameter (aiming distance) b could be determined as the distance from the centre of the target particle to the straight line, continuing the initial undisturbed trajectory of the incoming bombarding particle. The supposition about stochastic distribution of the aiming distances during the bombarding helped to solve the inverse problem and to determine the structure of atom. The formula by Rutherford has many confirmations, obtained in controlled experiments in the field of atomic physics (Born, 1963). It should be added, that all the confirmations correspond to the same scheme of experiments, keeping the validity of pair collision approximation.

L.D.Landau was the first, who applied Rutherford formula to the quite different spatial situation, arising in a volume with completely ionized plasma. Of course, no pair collisions can occur in this case. This circumstance sometimes was pointed out (Koga, 1970), but sometimes was not (Krall and Trivelpiece, 1973). The model of fully ionized plasma with so called "Coulomb collisions" dominates in textbooks on plasma physics (Clemmow and Dougherty, 1969; Landau and Livshits, 1979; Klimontovich, 1982). Theory of "weak plasma turbulence", criticizing model of pair interaction, uses this notion as well (Tsytovich, 1971).

There are several congruent ways to count the result of these "Coulomb collisions", e.g., on the deflection angle of a probing particle: to calculate a diffusion in the impulse phase space (Landau, 1937); to apply Fokker-Planck equation (Shkarofsky et al., 1966); to calculate a mean square deviation of deflection angle for a probing particle (Krall and Trivelpiece, 1973); to develop special diagram method (Balescu, 1963); to use BBGKY chain with hypothesis about weakening of correlations (Klimontovich, 1982). These methods are interrelated and use the same system of suppositions (Koga, 1970). All of them give the logarithmic divergence after integration over collision parameter b: final results contains $\int_0^\infty db/b$. The divergence is eliminated with the aid of the hypotheses, that b_{min} (minimal value of b) should be equal to λ_{DB} (De Broglie wave length) and b_{max} (the maximal value of b) should be equal to R_D (Debye radius of screening in plasma) – see (Krall and Trivelpiece, 1973). We shall discuss both hypotheses below. But the matter is that the divergence is caused by quite other reason. It is the non-pair nature of particle interaction in fully ionized plasma (Chertkov, 1998a).

2.4. Divergence of BBGKY Chain for Completely Ionized Plasma.

The most detailed analysis of system of postulates, basing BBGKY chain, and, respectively, the related methods, was given in the work (Koga, 1970). Let us recall, that Liuville equation is equivalent to the full system of Newton equations for the system of interacting particles and has no statistical character; it has the shape $(d/dtD^{(N)})_{along} = 0$. Here $D^{(N)}$ is the density of points, representing our system of N interacting particles in phase space; it is a function of $6N + 1$ variables: $\mathbf{r}_1, ...\mathbf{r}_N, \mathbf{p}_1, ..\mathbf{p}_N, t$; $\mathbf{r}_1, ...\mathbf{r}_N$ are radius-vectors of particles; $\mathbf{p}_1, ..\mathbf{p}_N$ are their impulses; t is the time. "Along" means, that the full time derivative is taken along the phase trajectory, along which the evolution of the state of our system occurs. The transition from Liuville equation to BBGKY chain was made under special assumption, that $D^{(N)}$ has a symmetry relative to rearrange of coordinates and impulses of any two particles. This assumption puts very essential conditions for dynamical processes, which could be described by the chain. Let τ_1 be a characteristic time scale of main movement in the system; τ_2 be the same for fluctuations; let $\tau_1 >> \tau_2$; The symmetry can arise from averaging over time τ_{12}, when $\tau_{12} << \tau_1$ and $\tau_{12} >> \tau_2$ (Poincaré, 1910). Liuville equation keeps information about initial condition of the system. Statistical sense of averaging over time is following. It is equivalent to the set of suppositions about the interaction of particles. The main suppositions are: (1) if the interaction between the particles is weak, mutual effect of two particles, colliding with the i-th particle during the time τ_{12}, should be small; (2)if the interaction is strong, the time τ_{12} should be enough small in order to the i-th particle can interact not more than with one particle during this time. It is necessary, that there exists a hierarchy of time scales: $\tau_1 >> \tau_2 >> \tau_3 >> ...$, where τ_1 is a characteristic time of external and macroscopic forces; τ_2 is the same of pair interaction; τ_3 is the same of perturbation of pair interaction from a third particle, and so on. Thus, BBGKY chain becomes irreversible on account of the way of averaging of the chain equations.

The conditions, necessary for obtaining of BBGKY chain, limit the possibility of its applications. The main conditions are: (1) time scales, used at obtaining of the chain, should coincide with time scales of dynamical processes in real systems; as a consequence, only two first equations of the chain have a certain physical sense; (2) the gas should be rarefied enough in order to two particles, interacting with the i-th particle consequently during the time τ_2, do not effect mutually in this time interval; (3) the gas should be dense enough, in order to distribution of particles in the vicinity of i-th particle can be assumed as a uniform one and a hypothesis like Stosszahlansatz can be applied; (4) the time scale of external force should be much more than τ_{12}.

The possibility of constructing of kinetic theory on the base of BBGKY chain depends upon the properties of modeled real system. It is obvious, that the condition (2) cannot be satisfied for Coulomb interaction. Most probably, that $\tau_2 \approx \tau_3 \approx \tau_4 ....$ But in this case no Debye screening effect should occur in electron gas. Divergence of integral of collision for Coulomb interaction is caused by the neglecting of interaction between field particles (Koga, 1970).

The final result of BBGKY chain for fully ionized plasma is a combination of Vlasov equation (a regular part, keeping memory about prehistory) with an integral of collisions for Coulomb interactions (a stochastic part, bringing relaxation to equilibrium state). Divergence of integral usually is eliminated by introducing of Debye screening.

2.5. Debye screening.

Debye screening was suggested for explanation of behavior of diluted solutions of strong electrolytes in water (Debye and Hückel, 1923). Mean electrostatic potential ψ is determined by Poisson equation $\Delta\psi = -4\pi\rho/\varepsilon$, where mean charge density ρ is obtained from the equilibrium Boltzmann distribution $\rho = \Sigma_i e z_i n_i exp(-e z_i \psi/kT)$; ε is the dielectric constant, e is the electron charge, z_i is the valence of i-th ion, n_i is the concentration of i-th ions, k is the Boltzmann constant, T is the temperature. Under the condition of electric neutrality $\Sigma_i n_i z_i = 0$; the condition of smallness of electrostatic interaction in comparison with the thermal energy $|e z_i \psi| << kT$; and boundary conditions at $r \to 0$: $\psi \to e z_i/(\varepsilon r)$, and at $r \to \infty$: $\psi \to 0$ the solution of Poisson equation is $\psi = (1/\varepsilon r) e z_i exp(-r/R_D)$, where $R_D = (4\pi e^2 \Sigma_i z_i^2 n_i/(\varepsilon kT))^{-1/2}$ is the radius of Debye sphere of ion screening. Comparison of the theory with experiments demonstrated very good agreement but only for $z_i = 1$ and for mole concentration in the range of 0.0001 - 0.001 (Moelwyn-Hughes, 1961; Izmailov, 1966). Diluted solutions of strong electrolytes are very simply reproducible systems and they were studied very thoroughly, in contrast to fully ionized plasma. Enhancement of mole concentration immediately led to breaking of condition $|e z_i \psi| << kT$. For our investigation it is important, that the theory is valid, only when Coulomb interaction is a small addition to the main interaction in the system, i.e., the thermal collision interaction between neutral molecules of water, which establishes the thermal equilibrium, and, respectively, Maxwell-Boltzmann equilibrium distribution function (Antropov, 1969).

The theory of low temperature partially ionized plasma has no conflicts with experiments (Zhukov and Ovsyannikov, 1994). All controlled physical experiments, confirming the model of "Coulomb collisions", were made in partly ionized plasma with very low ionization (10^{-5}) (Dougal and Golstein, 1958; Kulik et al., 1984; Yakubov, 1993; Fortov and Yakubov, 1994). Very low ionization can create conditions, approximately similar to pair Coulomb interactions with continuous stochastization, caused by collisions with neutral components. The point is that short-ranged interactions have quite different properties in comparison with long-ranged ones (Chertkov, 1997a; Chertkov, 1998a). There are no mechanisms to establish Debye screening in completely ionized plasma (Koga, 1970); that is why usually it was introduced "by hand" with no explanations and no justifications.

2.6. Boltzmann Collisions.

In 1872 L.Boltzmann suggested the kinetic equation, which, according to his opinion, explained the Second principle of thermodinamics – the law of enhancement of entropy in a closed system (Boltzmann, 1909): $[(\partial/\partial t)+\mathbf{v}(\partial/\partial\mathbf{r})]f = I_c^B$. Here $f = f(\mathbf{r}, \mathbf{v}, t)$ is the distribution function of particles over components of coordinates $\mathbf{r}$, velocities $\mathbf{v}$ and the time t. The kinetic equation contains a regular part (the left side) and a statistical one (the right side), which was called "the integral of collision". Calculations of I_c^B incorporated the energy conservation low, the impulse conservation low, and Stosszahlansatz. The last is equivalent to a supposition, that after each individual collision the particles are scattered over full solid angle 4π with equal probability. This approach was criticized by E.Zermelo, J.Loschmidt, and H.Poincaré (Haitun, 1996). They pointed out, that Stosszahlanzatz is incompatible with Newton mechanics. L.Boltzmann changed his substantiation several times (Boltzmann, 1909). But later, in XX century, it turned out, that Boltzmann approach can be very useful for many applications (Liboff, 1969; Balescu, 1975; Cercignani, 1975). However, the problem of substantiation of Stosszahlanzatz remained non-solved.

E.Hopf and N.S.Krylov (Hopf, 1939; Krylov, 1950), examining the model gas of rigid spheres, demonstrated, that slight disturbances of trajectories of colliding rigid spheres give very quick amplifying of initial angular disturbance for individual particle at consequent collisions – Figure1. This amplifying at every collision is proportional to the

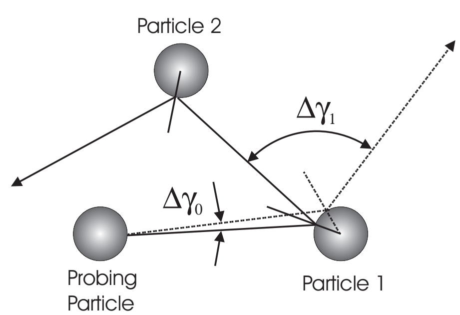

Figure 1. Amplifying of initial angular deflection from undisturbed trajectory by collision in gas of rigid spheres. Continuous lines represent the undisturbed trajectory; dashed lines represent the disturbed one; $\Delta\gamma_0$ is initial deflection angle; $\Delta\gamma_1$ is the deflection angle after first collision.

ratio (l/a), where l is mean free path in the gas and a is the radius of the sphere. As the mechanism of amplifying acts independently throughout the space for all the particles, it leads to the very quick phase mixing, to the loss of information about previous microscopic state of the gas. Physical sense of this was analyzed in the work by Yu.A.Kravtsov, who calculated the influence of some real sources of disturbances for real gases (Kravtsov, 1989). Let Δr_0 be a mean square root transversal displacement of trajectory of an individual particle during its movement between collisions, caused by slight fluctuating fields. Enhancement of transversal displacement Δr is proportional to $\Delta r_0(l/a)^{t/t_0-1}$, where t_0 is the time between collisions. After the time $t_R = t_0[\ln(l/\Delta r_0)/\ln(l/a)]$ it will be $\Delta r = a$ and every particle will lose all the memory about its previous movement. The influence of an ordinary thermal electromagnetic field with a temperature about 300K on the real air neutral molecules due to induced electric dipole moment gives the value $\Delta r_0 \approx 10^{-14}$cm; at $l \approx 10^{-4}$cm and $a = 10^{-8}$cm the amplifying coefficient is $K_A \approx l/a \approx 10^4$, and $t_R \approx 2.5t_0$. It means, that after second collision every particle of the air at normal conditions loses information about its prehistory. For smaller influence (e.g. interaction with neutrino) the result very slightly depends upon its intensity: for $\Delta r_0 \approx 10^{-1000}$cm will be $t_R \approx 250t_0$. The actual disturbing agent – the 300K electromagnetic field – passes to the air the energy about 10^{-20} of the internal energy of the air, and during the time about $10^{-8} - 10^{-9}$s all the particles, and the system as a whole, lose the memory about prehistory (Kravtsov, 1989).

We should draw attention to the simplicity and effectiveness of this mechanism of stochastization. It is the real stochastizator, acting in different systems with short-ranged interactions. Only for these systems the values of l and a are finite and $K_A > 1$ (Zaslavsky, 1984; Zaslavsky and Sagdeev, 1988). Similar processes could take place from interaction with low-frequency photons and phonons instead of 300K electromagnetic fields (Herzenstein and Kravtsov, 1998). The essential in this stochastization mechanism is the amplifying. Presence of an effective real stochastizator in systems with short-range interaction justifies the assumptions, made during the obtaining of Boltzmann equation and BBGKY chain. Moreover, it justifies the thesis by L.Boltzmann, that the Second principle of thermodynamics can be derived from Newton equations. It means, that the Second principle is not a prime law of nature, but it is a secondary one, derivable from prime laws under special conditions for certain situations (Chertkov, 1998a).

But *there is no process of rapid loss of previous information in the space fully ionized electron-proton plasma far from macroscopic conductors* (Chertkov, 1997a; Chertkov, 1998a). It is connected with long-ranged character of Coulomb forces. There is no amplification, $K_A = 1$. And it is the central point of our review.

2.7. Consequences of Absence of Stochastizator in Space Fully Ionized Plasma.

As we have seen in sect.2.6, it is the real stochastizator, that provided the validity of statistical approximations in mentioned fields of physics. It cannot be the way of averaging of initial Liuville equation, as it was declared sometimes – compare with (Koga, 1970), sect.2.4. But in a case of fully ionized space electron-proton plasma, when an effective stochastizator is absent, an eventful surprise waits for theoreticians: all the statistical methods for main processes (including correlation functions, Markov processes, Fokker-Plank approach, BBGKY chain) are invalid; the notion of probability cannot be applied to evolution of the system; fully ionized plasma is an object of the theory of dynamical systems and not of the statistical physics (Chertkov, 1997a; Chertkov, 1998a). There is no probability without honest mixing, it is known since Pascal times. The probability as a notion is determined from the hypothesis about equal *a priori* probabilities (Yaglom and Yaglom, 1973).

The construct "Coulomb collisions" is a profound failure of theoretical physics in XX-th century. Explicating the process of calculations in framework of this concept, we can see, that calculations imply the existence of several special mechanisms: 1) for switching on the pair interaction between the probing particle and the 1-st field particle, all the other field particles being switched off; 2) for switching off the 1-st field particle after a small time period, and mixing all the particles and their velocities; 3) for choosing the 2-nd field particle and switching on the pair interaction between the probing particle and the 2-nd one, and repeating the process. It is obvious, that this calculation cannot be a good first approximation to the processes in any real fully ionized plasma. Very roughly something like that can occur in partially ionized plasma at very low level of ionization. A clear evidence of misunderstanding of the problem is denomination of Vlasov equation with the selfconsistent field as "Boltzmann equation for Coulomb plasma", practicized in almost all textbooks. Vlasov equation, keeping entropy, is valid for real fully ionized plasma, but only in original interpretation of its author (Chertkov, 1998a).

Just the same error exists in theoretical astrophysics for long-ranged gravitation forces: the mean free path in gravitating systems of many bodies was evaluated using image of "gravitational collisions" (Chandrasekhar, 1942; Spitzer, 1987). The result was the same as in plasma physics – the logarithmic divergence. There is no possibility to check directly the dynamical evolution of gravitational clusters by controlled experiments or by observations. Debye screening is absent for gravitation forces, and to "cure" the divergence, the solutions with expanding Universe were suggested (Bisnovatyi-Kogan and Shukhman, 1982; Zakharov, 1984). But observations rather are incompatible with this hypothesis of expanding Universe (Vaucouleurs, 1970; Troitskii, 1993; Troitskii, 1996). To obtain a correct solution of problems in gravitational many body problems, there are some simple recipes: the systems should be finite; the initial state should be stable or, at least, not catastrophically unstable, because to study a slow instability on a background of a quick one is useless (Polyachenko and Fridman, 1976). These recipes are valid for plasma physics, but usually they do not used (Chertkov, 1997a). As a very characteristic example we can analyze "collisionless damping".

2.8. Collisionless Damping in Fully Ionized Plasma

One of the central topics in modern plasma physics is the "collisionless plasma damping" (Landau damping). It is a subject of any textbook in this field. Solving Vlasov equation, which is reversible in time and keeps entropy, L.D.Landau obtained damping of oscillations in collisionless plasma (Landau, 1946). A standard interpretation of the damping is following. It is the result of interactions of electrons, having velocity v_x, and a plasma wave, having phase velocity ω/k (ω is angular frequency and k is module of wave vector). The wave with $\omega/k > v_x$ gives its energy to the electrons; the wave with $\omega/k < v_x$ receives energy from the electrons. Maxwell distribution of electrons over velocities is a diminishing function, that is why there is a damping of the wave (Landau and Livshits, 1979). F.F.Chen stated, that this simple linear treatment is reversible in time, thus, it is inadequate and a non-linear treatment is required. But some paradoxes appear in the next approximation as well (Chen, 1984). I.A.Kvasnikov, discussing this interpretation of Landau damping, noticed, that the model, in framework of which this inference was made, do not contain the description of very this interaction wave-electron, because Vlasov equation do not describe point-like electrons (Kvasnikov, 1987). Yu.L.Klimontovich pointed out to the true collisional nature of the damping (Klimontovich, 1997). V.N.Soshnikov paid attention to the fact, that Sokhotsky-Plemelj formula, and, respectively, all the result by Landau, stems from only one of variants of performing the double limit transition in initial integration. The result depends upon the details of limit transitions. Sokhotsky-Plemelj formula is only a special case, and not a general solution. The result, directly opposite to the one by Landau, i.e., integration over an other contour, has the same rights for existence. E.g., there are physically natural solutions in a shape of non-damped standing waves. Cauchy-Riemann conditions are not fulfilled for analytical continuation (Soshnikov, 1991). There are difficulties with reproducing of Landau damping in numerical calculations; the direct confrontation is very complicated because Landau damping is an asymptotical result; it is unclear how to formulate the boundary conditions in numerical calculations (Birdsall and Langdone, 1985). Comparison with controlled experiments were made for spatial damping instead of temporal (Chen, 1984). All the controlled experiments referred to the partly ionized plasma with predominant role of collisions with neutral atoms (Krall and Trivelpiece, 1973).

Comparison of solutions of the same problem, suggested by different authors, revealed the contradictions. Let us discuss the correspondence of the initially stated formulation of the problem and the problem, which in fact was solving in L.D.Landau work. The initial distribution function – Maxwell one – $f^M(\mathbf{r}, \mathbf{v}, t)$ is not natural for Vlasov equation, because this equation contains no mechanisms to establish this function, but it is admissible; and, probably, a special tool have prepared this initial function and then the tool was switched off; but the condition, that the first approximation distribution function $f_1(\mathbf{r}, \mathbf{v}, t)$ is much less, than $f^M(\mathbf{r}, \mathbf{v}, t)$, requires a new special tool, acting throughout the space and providing this condition. The role of this tool can play: (1) a non-ionized component of plasma; (2) a macroscopic conducting wall, which can damp plasma oscillations; (3) special beings, relatives of Maxwell demon. The action of this tool is of prime importance for the regarded problem, but it never was mentioned in initial formulation of it (Chertkov, 1998a). The problem, which really was solving, should be formulated with following addition: to solve Vlasov equation, *when a special mechanism, keeping Maxwell distribution, is working.* As Vlasov equation itself cannot preserve Maxwell distribution, some paradoxes appear. Several suggested ways of solution (Landau, 1946; Van Kampen, 1955; Van Kampen, 1957) used some different mathematical operations, which should correspond to a modification of initial formulation of the problem, introducing damping, which was not contained in Vlasov equation. Any statements, e.g., about analytical properties of integrated functions, corresponded to pre-solution of problem (Stix, 1963); to fulfill this pre-solution one should have a special tool (see above). But the solution is unstable relative to small change in this formulation (Soshnikov, 1991). The problem is badly posed in mathematical sense; it was used the equation, which is not adequate to the problem, when the problem is "to find damping".

Proper formulation of the problem should be the following: "to find the distribution function and the plasma waves, when initial conditions before $t = 0$ are set up in space and since $t = 0$ boundary conditions on boundary surfaces are set up". It is a very complicated problem. In this formulation it never was solved (Galeev and Sagdeev, 1984).

So, we can see, that the combination of mentioned simplifying conditions implicitly introduces in calculations a process of the rapid loss of information about the previous state of plasma. Sometimes processes of that kind can take place: e.g., cases (1) and (2), but there is no such a device in a real stellar wind or inside a star (Chertkov, 1998a). All the paradoxes of the theory can be eliminated by introducing Boltzmann gas into collisionless plasma (Stix, 1963), but it does mean, that no collisionless damping can occur in a fully ionized plasma.

3. New Concept of Fully Ionized Space Plasma.

Thus, fully ionized space plasma must be an object of a theory of dynamical systems – sect.2.7. Only few methods can adequately describe this plasma. They are: (1) Vlasov equation (in original interpretation of its author); (2) direct computer modeling of Coulomb interaction between protons and electrons (Chertkov et al., 1989; Mayorov and Yakovlenko, 1994; Chertkov and Shalyapin, 1999); (3) phenomenological modeling with *a posteriori* determination of parameters of modeled medium (Chertkov, 1985; Chertkov, 1992; Chertkov, 1994b).

The empirical estimate of plasma electrical conductivity in the solar wind near the orbit of the Earth $\sigma \approx 2 \cdot 10^1 \mathrm{s}^{-1}$ and near the Sun $\sigma \approx 2 \cdot 10^3 \mathrm{s}^{-1}$ was made from comparison of the observed radial gradients of the interplanetary magnetic field and the calculated ones (Chertkov, 1985; Chertkov, 1992). Small systematic deviations from Parker spirals turned out to be important. This estimate does not follow from the standard plasma theory. It differs from the value given by Spitzer (Spitzer, 1962) by $10^{13} - 10^{14}$ times. It must be noted, that this value of σ should be treated with caution. Due to the method of obtaining it may be used only for "large- scale" description of slow processes similar to the solar coronal expansion. It cannot be valid for quick processes, strongly changing the state of the plasma, e.g. for the process of interaction of this plasma with planetary magnetospheres.

Using this estimate, a model with induction heating of corona and acceleration of the solar wind was suggested. The observed slow changes of solar super-large-scale magnetic fields are sufficient to account for the observed coronal power and solar wind power (Chertkov and Arkhipov, 1994; Chertkov et al., 1998; Chertkov, 1999).

To explain this key empirical estimate of σ on the microscopic level, we should understand, what are causes of the observed state of plasma. The plasma in the solar wind cannot be in the state close to the local thermodynamical equilibrium: non-thermal processes of the solar wind creation (induction heating) and absence of quick stochastization prevent it from relaxation to this state. The doubling of a characteristic volume of plasma, moving in the solar wind out of the Sun with hypersonic velocity, is more rapid process, than the process of relaxation for the pressure in this volume. This twofold increasing of the volume is connected with a huge energy transfer through its surfaces; the transferred energy is more than the total internal energy, contained in the volume. Empirical data confirm the existence of non-equilibrium phenomena in the solar wind. Contemporary plasma theories are based on the supposition that the energy fluxes through plasma are small and, hence, the plasma state is close to the local thermodynamic equilibrium. But the observed heat transfer in the solar wind can be provided only by non-chaotic electron movements. They are induction electric currents, creating the solar wind (Chertkov, 1994b).

Analysis of conditions for plasma in the solar wind and inside the Sun allowed to suggest a new concept for space fully ionized plasma. The main features of the new plasma model are the following. There is almost no chaos in the fully ionized electron-proton plasma. A substantial part of internal energy in plasma is contained in some non-degenerate forms. Big portions of electrons have definitely directed but not chaotic velocities. Debye screening is not complete both in space and time: all the particles systematically move, being specially organized. The main process in plasma is the simultaneous (parallel) interaction of particles with excitation of the powerful resonant self-consistent electric field. This field is created by quasi-regular structures - oscillating cells, "dynamical crystals" - with characteristic sizes about the radius of Debye sphere and with frequencies about plasma frequencies for electrons and protons. Spatial and temporal shape of these oscillating cells are similar to well known convective cells with cooperative toroidal movements of particles. Separate movements of protons and electrons provide strong interaction between these different kinds of particles. The cells form the oscillating systems of higher order - sublattice for electrons and sublattice for protons. The first is in the state of faster moving, while the second moves relatively slowly. Between these two sublattices there is strong interaction. They are mutually embedded. On the macroscopic level it leads to a possibility of hydrodynamical description of plasma. The plasma is similar to a dielectric with positive full energy (in absence of gravitation field). The new class of plasma waves should appear - the transversal waves similar to the same waves in ordinary solid bodies (Chertkov, 1985; Chertkov, 1994b).

The suggested model should be checked. The measurements of electric fields of plasma oscillations in the solar wind could be a crucial experiment. But a metallic vehicle does with the primordial plasma oscillations in the solar wind just the same as every person does with the Earth's vertical electrostatic field: in the presence of a person this field is equal to zero, but in the absence it is 100 V m^{-1} and the most of people has no notion about it. The traditionally measured electrostatic fields in the solar wind is not the primordial ones but the result of a plasma-vehicle interaction. A theory of this interaction is not complete now. The relative value of measured plasma wave electric fields should be correct. In frame of the suggested new concept the spacecraft must suppress the primordial oscillations in its vicinity. The correct measurements could be made with the use of micro-electroscope, moving in plasma and observed from spacecraft (Chertkov, 1994b).

The resonant properties of three-dimensional plasma cells were investigated by numerical simulation (Chertkov et al., 1989; Chertkov and Shalyapin, 1999). The adopted parameters correspond to the conditions occurring in the solar interior, but the results could be of interest for other objects with completely ionized plasma under conditions quite different from local thermodynamical equilibrium. Equal number of protons and electrons, interacting according to Coulomb law, move inside a cubic box. The particles have finite sizes equal to De Broglie wave length λ_{DB}, their electric charge is distributed over this volume; it prevents a process of imploding for particles with different charges. Specifically directed alternating in time external electric fields, applied only near the surfaces of the box, arise powerful resonant oscillations of plasma. The energy of oscillations are comparable with the total energy contained in this volume. The amplitude of this external field is the same as the amplitude of presupposed oscillations, which are set up in ambient plasma. So, the investigated oscillations are searching under condition, that they are established in the vicinity of the modeled box. Boundary conditions are made maximally favorable for excitation of resonant oscillations in the box. The result is the following: a time-space self-organization occurred in the box; several closely linked rotationally-oscillatory structures appeared in the box; they are similar to convective toroidal structures; the characteristic size is Debye radius; the characteristic frequency is plasma frequency. Only electron movements were investigated. The result confirms the new model of fully ionized plasma.

Controlled experiments confirm the existence of regular space-time structures in completely ionized plasma. The details of structures cannot be determined by unique way (Berezin et al., 1983).

4. Conclusion

We saw, that the image of "Coulomb collision" with the properties of Boltzmann collisions played the key negative role in physics of fully ionized plasma. To compensate the heavy errors in evaluating of real space plasma parameters, which were connected with this image, the theory of "fast spontaneous magnetic re-connection" (Petschek's model) was invented. In contrast to "Coulomb collision" theory, the last theory contains obvious errors (Chertkov, 1994a; Chertkov, 1997b). But the consequences of the first theory are much serious. J.N.Bahcall, who gave a fine analysis of solar neutrino problem in the monograph (Bahcall, 1989), wrote (inverse translation from Russian): "the ratio of the time period between strong Coulomb collisions, which aim for restoring of Maxwell distribution, to the time period between reactions of synthesis, which ruin this distribution, is $r \approx 10^{-22} - 10^{-30}$; that is why even for the tail of distribution there is a reserve of twenty orders in magnitude". J.N.Bahcall absolutely precisely reproduced the main idea of contemporary plasma physics. It is the identification of artificial construct "Coulomb collision" with real Boltzmann collision. The identification is incorrect and leads to conflicts of the theory and experiments – see sect.1. We saw, that the supposition about loss of microscopic information in fully ionized space plasma was connected with inadequate calculation method. The new concept sect.3 allows one to calculate a series of models for internal Sun to solve the problem of solar neutrino. It could be done with the new distribution function for plasma: oscillating one (Chertkov, 1985; Chertkov, 1998c).

The new concept radically changes the way of description of space plasma. All the notions, based on probability (e.g., correlation functions) should be used in quite different sense - closer to the one, used for regular structures with small chaos (Klimontovich, 1990).

The problems for the solar wind, mentioned in 2.1, could be solved in the framework of the model of induction heating, based on the new plasma concept sect.3 (Chertkov, 1994b).

References

Akhiezer, A.I., I.A. Akhiezer, R.V. Polovin, A.G. Sitenko, and K.N. Stepanov, *Electrodynamics of Plasma.* Nauka Publ.: Moscow, 720p., (in Russian), 1974

Alfvén,H., *Cosmic Plasma.* D.Reidel Publ.Co., Dordrecht: Holland, 212p., 1981.

Alfvén,H., and G.Arrhenius, *Evolution of the Solar System.* NASA SP-345, Washington, D.C., 520p., 1976.

Antropov,L.I., *Theoretical Electrochemistry.* Vysshaya Shkola Publ.: Moscow, (in Russian), 512p., 1969

Bahcall,J.N., *Neutrino Astrophysics.* Cambridge Univ. Press, Cambridge, MA, 624p., 1989

Balescu,R., *Statistical Mechanics of Charged Particles.* Interscience Publ., A Div. of John Wiley and Sons, Ltd.: London, 516p., 1963

Balescu,R., *Equilibrium and Nonequilibrium Statistical Mechanics.* A Wiley-Interscience Publ., John Wiley and Sons: New York, 790p., 1975

Baranov,V.B., and K.V.Krasnobayev, *Hydrodynamical Theory of Cosmic Plasma.* Nauka Publ.: Moscow, 336p., (in Russian), 1977

Berezin,A.B., B.V.Lyublin, and G.D.Yakovlev, Investigation of Plasma Turbulence in Quick Theta Pinch using Stark Broadening of Deuterium Spectral Lines, *J. Tech. Phys. (Rus.)*, 53(4)642-652, 1983

Birdsall,C.K., and A.B.Langdone, *Plasma Physics via Computer Simulation.* McGrow Hill Book Co., 452p., 1985

Bisnovatyi-Kogan,G.S., and I.G.Shukhman, Collisions in Expanding Universe, *J. Exp. Theor. Phys. (Rus)*, 82(1)3-8, 1982

Bogolyubov,N.N., *Problems of Dynamical Theory in Statistical Physics.* Gostechizdat Publ.: Moscow-Leningrad, 120p., (in Russian), 1946

Boltzmann,L., *Wissenschaftliche Abhandlungen.* Hasenorl F., ed., J.A.Barth: Leipzig, Bd.2, 550p., (in German), 1909

Born,M., *Atomic Physics.* Blackie and Son Ltd.: London and Glasgow, 490p., 1963

Born,M., and H.S.Green, A General Kinetic Theory of Liquids, *Proc. Roy. Soc. London Ser.A,* 188,10-18, 1946; 190,455-473, 1947

Brandt,J.C., *Introduction to the Solar Wind.* W.H.Freeman and Co.: San Francisco, 206p., 1970

Chandrasekhar,S., *Principles of Stellar Dynamics.* Yerkes Obs. Press, 264p., 1942

Cercignani,C., *Theory and Application of the Boltzmann Equation.* Scottish Academic Press: Edinburgh and London, 496p., 1975

Chen,F.F., *Introduction to Plasma Physics and Controlled Fusion. v.1. Plasma Physics.* Plenum Press: New York and London, 398p., 1984

Chertkov,A.D., *Solar Wind and Internal Structure of the Sun.* Nauka Publ.: Moscow, 200p., (in Russian), 1985.

Chertkov,A.D., Magnetic Field of the Solar Wind: A Stationary Kinematic Solution with a Finite Electric Conductivity, In: E.Marsch and R.Schwenn, eds., *Solar Wind Seven, COSPAR Coll. Ser. vol.3,* Pergamon Press, Oxford, p.165-168, 1992

Chertkov,A.D., Critical Analysis of "Re-connection" Theory (Petschek's Model), In: D. Baker, V. Papitashvily, and M. Teague, eds., *Proc. 1992 STEP/5th COSPAR Coll.*, Pergamon Press, Oxford, p.235-238, 1994a

Chertkov,A.D., Microscopic Structure of Plasma in the Solar Wind, ibid., p.803-806, 1994b

Chertkov,A.D., Formulations of Problems in Plasma Kinetics for Solar Wind and Sun's Interior, In: M.I.Pudovkin, B.P.Besser, W.Riedler, and A.M.Lyatskaya, eds., *Problems of Geospace*, Austrian Acad. Sci. Publ., Wien, p.179-186, 1997a

Chertkov,A.D., Magnetic Field Line "Re-connection": Incorrect Terminology or Incorrect Concept? ibid., p.187-198, 1997b

Chertkov,A.D., Analysis of Theories of Fully Ionized Space Plasma, In: V.I.Makarov, and V.N.Obridko, eds., *New Cycle of Solar Activity: Observational and Theoretical Aspects,* Pulkovo Obs. Publ., St.-Petersburg, p.395-398, (in Russian), 1998a

Chertkov,A.D., Variable Magnetic and Electric Fields in Corona and Solar Wind, ibid., p.399-402, 1998b

Chertkov,A.D., Solar Neutrino Problem and Theory of Internal Structure of the Sun, ibid., p.403-406, 1998c

Chertkov,A.D., Sun as Electric Engine for Creation of Corona and Solar Wind, In: V.I.Makarov, and V.N.Obridko, eds., *Large-scale Structure of Solar Activity: Achievments and Perspectives*, Pulkovo Obs. Publ., Sankt-Petersburg, p.315-320, (in Russian), 1999

Chertkov,A.D., and Yu.V.Arkhipov, Induction Heating of Corona and Acceleration of Solar Wind, In: D. Baker, V. Papitashvily, and M. Teague, eds., *Proc.1992 STEP/5th COSPAR Coll.* , Pergamon Press, Oxford, p.117-120, 1994

Chertkov,A.D., I.V.Golovchanskaya and V.A.Anisimov, Investigation of Resonant Properties of Plasma Oscillating Cell, In: *Magnetospheric Research*, Moscow, VINITI Publ., No12, p.106-110, (in Russian),1989

Chertkov,A.D., V.A.Anisimov, and V.A.Soldatov, Magnetic Electrohydrodynamics of Corona and Solar Wind, In: V.I.Makarov, and V.N.Obridko, eds., *New Cycle of Solar Activity: Observational and Theoretical Aspects,* Pulkovo Obs. Publ., St.-Petersburg, p.185-190, (in Russian), 1998

Chertkov,A.D., and V.Yu.Shalyapin, Model of Plasma in Solar Corona, In: V.I.Makarov, and V.N.Obridko, eds., *Large-scale Structure of Solar Activity: Achievments and Perspectives*, Pulkovo Obs. Publ., Sankt-Petersburg, p.305-308, (in Russian), 1999

Clemmow,P.C., and J.P.Dougherty, *Electrodynamics of Particles and Plasmas* Addison-Wesley Publ.Co., Inc., Redwood City,CA, 520p., 1969

Debye,P., and E.Hückel, Zur Theorie der Elektrolyte. I. Gefrierpunktserniedrigung und Verwandte Erscheinungen. II. Das Grenzgesetz für die Elektrische Leitfähigkeit. *Phys. Z.,* 24, 185-314; 315-360, (in German), 1923

Dougal,A., and L.Goldstein, Energy Exchange Between Electronic and Ionic Gases in Plasmas by Coulomb Collisions, *Phys. Rev.,* 109(3)615-630, 1958

Fortov,V.E., and I.T.Yakubov, *Non-ideal Plasma,* Energoatomizdat Publ.: Moscow, 367p., (in Russian), 1994

Galeev, A.A., and R.Z.Sagdeev, Current Instabilities and Anomalous Resistance of Plasma, In: *Principles of Plasma Physics.* Energoatomizdat Publ.: Moscow, v.1, 640p., 1983; v.2, 632p., 1984; add. to v.2, 240p., 1984

Galeev, A.A., and R.Sudan, eds., *Principles of Plasma Physics.* Energoatomizdat Publ.: Moscow, v.1, 640p., 1983; v.2, 632p., 1984; add. to v.2, 240p., 1984

Gibson, E.G., *The Quiet Sun.* NASA Publ: Washington, 408p., 1970

Ginzburg,V.L., L.D.Landau, M.A.Leontovich, and V.A.Fock, About Inconsistency of Works by A.A.Vlasov on General Theory of Plasma and Physics of Solid Body, *J. Exp. Theor. Phys. (Rus)*, 16(3)246-252, 1946

Gott,Yu.V., and E.I.Yurchenko, Electrostatic Non-quasineutral Turbulency and Ion Heat Transfer in Tokomak, *Phys. of Plasma (Rus.)*, 22(1)16-24, 1996

Haitun,S.D., *Mechanics and Irreversibility.* Yanus Publ: Moscow, 448p., 1996

Herzenstein,M.E., and Yu.A.Kravtsov, Quantum Nature of Origin of Randomness and Irreversibility at Collision of Neutral Atoms, *Sci. and Technol. in Russia (Rus.)*, 6(29)9-11, 1998

Hopf,E., Statistik der Geodätischen Linien in Mannigfaltigkeiten Negativer Krümmung, *Ber. Verh. Sächs. Akad. Wiss. Leipzig,* Bd.91, p.261-304, (in German), 1939

Hundhausen,A.J., *Coronal Expansion and Solar Wind.* Springer Verlag: Heidelberg, New York, 302p., 1972

Izmailov,N.A., *Electrochemistry of Solutions.* Chimiya Publ.: Moscow, 576p., (in Russian), 1966

Kirkwood,J.G., The Statistical Theory of Transport Processes. I. General Theory. *J Chem.Phys.,* 14,180-201, 1946

Klimontovich,Yu.L., *Statistical Physics.* Nauka Publ.: Moscow, 608p., (in Russian), 1982

Klimontovich,Yu.L., *Turbulent Motion and Structure of Chaos: A New Approach to Theory of Open Systems.* Nauka Publ.: Moscow, 316p., (in Russian), 1990

Klimontovich,Yu.L., Physics of Collisionless Plasma, *Usp. Fiz. Nauk (Achiev. Phys. Sci.) (Rus)*, 167(1)23-55, 1997

Koga,T., *Introduction to Kinetic Theory.* Pergamon Press, Oxford, 272p.,1970

Krall,N.A., and A.W.Trivelpiece, *Principles of Plasma Physics* . McGraw-Hill Book Co., New York, 526p., 1973

Kravtsov,Yu.A., Actual Limits of Closure Hypothesis and Classical Paradoxes in Kinetic Theory, *J. Exp. Theor. Phys. (Rus)*, 96(5)1661-1665, 1989

Krommes,J.A., Renormalizations in Physics of Plasma, In: Galeev, A.A., and Sudan,R., eds., *Principles of Plasma Physics.* Energoatomizdat Publ.: Moscow, v.2, p.174-266, 1984

Krylov,N.S., *Works on Substantiations of Statistical Physics.* Acad. Sci. Publ., Moscow-Leningrad, 208p., (in Russian), 1950

Kulik,R.E., B.A.Ryabyi, and N.V.Ermokhin, *Non-ideal Plasma.* Energoatomizdat Publ.: Moscow, 200p., (in Russian), 1984

Kvasnikov,I.A., *Thermodynamics and Statistical Physics. Theory of Non-equilibrium Systems.* Moscow University Publ.: Moscow, 559p., (in Russian), 1987

Landau,L.D., Kinetic Equation in Case of Coulomb Interaction, *J. Exp. Theor. Phys. (Rus)*, 7(2)203-210, 1937

Landau,L.D., About Oscillations of Electron Plasma, *J. Exp. Theor. Phys. (Rus)*, 16(6)574-590, 1946

Landau,L.D., and Livshits,E.M., *Theoretical Physics*, vol.10: Livshits,E.M., and Pitayevsky,L.P., *Physical Kinetics*, Nauka Publ., Moscow, 528p, (in Russian), 1979

Liboff,R.L., *Introduction to the Theory of Kinetic Equations.* John Wiley and Sons, Inc.: New York, 374p., 1969

Mayorov, S.A., and S.I.Yakovlenko, Development of Method of Dynamics of Many Coulomb Particles, *Izv. VUZ., Fiz. (Proc. High. School, Phys.)*, (in Russian), 37(11)44-56, 1994

Moelwyn-Hughes,E.A., *Physical Chemistry.* Pergamon Press: London, 1148p., 1961

Nakariakov,V.M., L.Ofman, E.E.DeLuca, B.Roberts, and J.M.Davila, TRACE Observations of Damped Coronal Loop Oscillations: Implications for Coronal Heating, *Science,* 285,862-864, 1999

Parker,E.N., *Interplanetary Dynamical Processes.* Interscience Publ., a Div. of John Wiley and Sons: New York - London, 364p., 1963

Poincaré,H., *Leçons de Mécanique Céleste.* Gauthier-Villars: Paris, (in French), t.1, 367p., 1905; t.2, pt.1, 167p., 1907; t.2, pt.2, 137p., 1909; t.3, 472p., 1910

Polyachenko,V.L., and A.M.Fridman, *Equilibrium and Stability of Gravitating Systems.* Nauka Publ.: Moscow, 448p., 1976

Rutherford,E., The Scattering of α and β Particles by Matter and the Structure of the Atom, *Phil.Mag.,* 21, 669-696, 1911

Schmidt,A.B, *Statistical Thermodynamics of Classical Plasma.* Energoatomizdat Publ.: Moscow, 120p., 1991

Shkarofsky,I.P., T.W.Johnston, and M.P.Bachynski, *The Particle Kinetics of Plasma.* Addison-Wesley Publ.Co., Reading, MA, 400p., 1966

Soshnikov,V.N., Langmuir Waves in Collisionless Plasma: Solution of Problem by L.D.Landau, *Dep. VINITY* No 2972-B90, 16.05.90; No 3361-B91, 23.07.91, (in Russian), 1991

Spitzer,L.,jr., *Physics of Fully Ionized Gases.* Sec.ed., Interscience Publ., J.Wiley and Sons, New York-London, 212p., 1962

Spitzer,L.,jr., *Dynamical Evolution of Globular Clusters.* Priceton Univ.Press, Princeton, NJ, 184p., 1987

Stix,T.H., *The Theory of Plasma Waves.* McGraw-Hill Book Co., Inc., New York, 344p., 1963

Troitskii,V.S., Astrophysical Observations Excludes the Hypothesis on the Universe Expansion, *Astrophys. Space. Sci.,* 201,203-221, 1993

Troitskii,V.S., Observational Test of the Cosmological Theory Testifies to the Static Universe and a New Redshift-Distance Relation, *Astrophys. Space. Sci.,* 240,89-121, 1996

Tsytovich,V.N., *Theory of Turbulent Plasma.* Atomizdat: Moscow, 424p., (in Russian), 1971

Van Kampen,N.G., On the Theory of Stationary Waves in Plasma, *Physica,* 21,(12)949-963, 1955

Van Kampen,N.G., Dispersion Equation for Plasma Waves, *Physica,* 23,(7)641-650, 1957

Vaucouleurs, de, G., The Case for Hierarchical Cosmology, *Science,* 167,1203-1210, 1970

Vlasov, A. A., About Vibrational Properties of Electron Gas, *J. Exp. Theor. Phys., (Rus.)* 8(3)291-318, 1938

Vlasov, A. A., *Theory of Vibrational Properties of Electron Gas and its Applications.* Sci. Rep. Moscow State Univ., v.75, Physics, book 2, Pt.1, 196p., (in Russian), 1945

Vlasov, A. A., *Theory of Many Particles.* Acad. Sci. Publ., Moscow-Leningrad, 348p., (in Russian), 1950

Vlasov, A. A., *Statistical Distribution Functions.* Nauka Publ.: Moscow, 356p., (in Russian), 1966

Vlasov, A. A., *Non-local Statistical Mechanics.* Nauka Publ.: Moscow, 264p., (in Russian), 1978

YaglomA.M., and I.M.Yaglom, *Probability and Information.* Nauka Publ.: Moscow, 512p., (in Russian), 1973

Yakubov,I.T., Electric Conductivity of Non-ideal Plasma, *Usp. Fiz. Nauk (Achiev. Phys. Sci.) (Rus)*, 163(5)35-51, 1997

Yerofeyev,V.I.,and V.M.Malkin, Kinetics of Weakly Turbulent Wave Fields, *J. Exp. Theor. Phys. (Rus)*, 96(5)1666-1697, 1989

Yvon,J., *La Théorie Statistique des Fluides et l'Equation d'Etat.* Hermann et Cie Publ.: Paris, 49p., (in French), 1935

Zakharov,A.V., Integral of Collision in Fridman World, *J. Exp. Theor. Phys. (Rus)*, 86(1)3-12, 1984

Zaslavsky,G.M., *Stochastity of Dynamical Systems.* Nauka Publ.: Moscow, 272p., 1984

Zaslavsky,G.M., and R.Z.Sagdeev, *Introduction to Non-linear Physics.* Nauka Publ.: Moscow, 368p., 1988

Zirin,H., *The Solar Atmosphere.* Blaisdell: Waltham, MA, 560p., 1966

Zhukov,M.F., and A.A.Ovsyannikov, eds., *Diagnostics of Low Temperature Plasma.* Nauka Publ.: Novosibirsk, 488p., (in Russian), 1994