RECOMBINATION IN STRONGLY COUPLED ION PLASMA AFTERGLOW OF GAS DISCHARGE.

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The goal of this works is to study of the recombination process in the plasma of positive and negative ions produced in the afterglow of gas discharge. Experimental study of the recombination process in this system showed a strong suppression of the recombination rate compared to the classical model [1] for the ion plasma consisting of fluoride or fluorides of sulfur. In this case, there is increasing deviation of the recombination rate from the results predicted by the classical model with increasing nonideality parameter of the system.

Explanation for these results is possible within the framework of approaches based on the use of molecular dynamics simulation, which allow a detailed description of the interaction between the ions and molecules produced plasma. This makes it possible to give an adequate description of the impact the formation of loose ion pairs to the recombination process in the plasma. An earlier study of the recombination process [2] showed that the increase of the plasma nonideality parameter should strongly suppress the recombination process. This is due to the formation of zones of manybody fluctuations between regions of the pair states and free electrons. In this case, the recombination rate should be described by the following formula:

$$K_e \tau_e = \begin{cases} 0.3 \cdot \Gamma^{9/2} & npu \quad \Gamma < 0.488 \\ 2.7 \cdot \Gamma^{9/2} e^{-A \cdot \Gamma} & npu \quad \Gamma > 0.488 \end{cases} \qquad (1)$$

where τ_e – the period of plasma oscillation, Γ - nonideality parameter, factor A = 4.5. The resulting ratio is consistent for the rates of recombination in an ultracold plasma. In the case of ion plasma this ratio also must maintain its applicability. In this case, the value of τ_e should take a formal value of $\tau = \sqrt{\pi m / e^2 n}$, where m - mass of light ion. This model is sufficient to describe the recombination processes in ion-plasma sulfur hexafluoride [1]. However, the magnitude of the factor A in this case exceeds the value of the electron-ion plasma and is equal to A = 6.75. This is due to an increase in the width of zones of many body fluctuations in ion plasma due to the destabilization of the pairs due to their collisions with the neutral molecules.

If in the case of sulfur hexafluoride proposed model can well describe the dependence of the recombination rate from the nonideality parameter, in the case of fluoride decrease the recombination rate with increasing non-ideality is significantly stronger than predicted by the model (1). The explanation for these results can be done under the assumption that the recombination process is strongly coupled ion plasma occurs in two stages. In the first stage is reversible formation of a loose ion pair, in which the recombining ions are separated by solvate shell. A second stage is a transition of loose ion pair in a tight ion pair with its subsequent recombination. In cases where the loose ion pair is unstable then the two-stage nature of the recombination has little effect on its kinetics and it is described by the model (1). If the activation energy of the decay of a pair is sufficiently high that in the case of ion plasma in fluorine, the rate-limiting phase is the second stage, which leads to an additional reduction in the rate of recombination in strongly coupled plasmas.

[1] Amirov R. Kh.// Dr Habilitus, Moscow, 2001

[2] A. Lankin, G. Norman // Contrib. Plasma Phys. 2009. V.49, No. 10. P. 723 – 731

New possibilities of cryogenic environment in dusty plasma structure formation.

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Levitation of dust particles and formation of ordered dust structures were observed in plasmas of the most various kinds: in thermal plasma, in gas discharges of various kinds and configurations, in nuclear-induced plasma. Dusty plasma structures were also observed in the cryogenic dc gas discharge [1]. Such systems received the name of cryogenic complex (dusty) plasma, i.e. dusty plasma where heavy neutral component is cooled down to cryogenic temperatures (<100 K). Considerable interest in cryogenic temperatures as conditions of dusty plasma structures formation is caused by the assumption that cryogenic dusty plasma allows to combine two approaches in study of strongly coupled Coulomb systems: first, the cooling the particle system and second, the increasing the energy of particles interaction in plasma.

It was obtained in [1] that cooling of the discharge down to 77 K at a constant discharge current leads to increase of kinetic temperature of dust particles. Besides, the proposition that reduction of interpartical distances at gas temperature decrease can lead to formation of super dense dust structures, where interparticle distance is comparable to particle size and Debye ionic radius of background plasma, was reliably proved. It was found that such dust structures have exotic properties such as globular (spherical) form, free boundaries, etc.

The present work is devoted to investigation of specific features of super dense dust structures formation in a dc glow discharge at cryogenic temperatures. Results on the experimental investigations of new phenomenon of *spheroidizing* – process of the dust structure transition to compact globular shape at cryogenic temperatures – were presented. Possible nature of such phenomenon is discussed.

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References.

1. Antipov S.N., Asinovskii E.I., Fortov V.E., Kirillin A.V., Markovets V.V., Petrov O.F., and Platonov V.I., Phys. Plasmas **14**, 090701 (2007).

PECULIARITIES OF THE NON-IDEAL PLASMA GENERATION UNDER THE IMPACT OF THE ELECTROMAGNETIC PULSE WITH THE SUB-NANOSECOND RISE ON MICROCONDUCTORS

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The main objective of the suggested work is the experimental investigation of the efficiency of the peculiarities of the non-ideal plasma generation under the impact of the electromagnetic pulse (EMP) with the sub-nanosecond rise on microconductors. The high-voltage impulse generator "RADAN-220" (with characteristic impedance of 50 Ω) was discharged to the inhomogeneous 15 cm long and 10 cm internal diameter coaxial line (vacuum chamber). To the central conductor there were placed 5–15 mm long microwires of Cu (20–300 μm in diameter), Ni (25 μm in diameter) and W (24.5–100 μm in diameter). Voltage pulse amplitude U_0 was of about 220 kV, pulse rise duration τ_f was of about 200–500 ps; energy w stored in the generator equals to 1 J. Pressure in the camera varied as $P = 10^{-4}$–760 Torr. The input voltage in the vacuum chamber was measured via the capacitance voltage divider installed into the vacuum oil. The electric current was measured via placed at the end of the line shunt with the impedance $R_{sh} = 0.4$ Ω and 5 GHz bandwidth. Signals from both shunt and divider were registered by the four-channel digital Tektronix oscilloscope with 1 GHz bandwidth. We also performed the integral survey of the discharge channel self glowing via the DSLR cameras Canon EOS 450D and Canon EOS 5D Mark II; its continuous sweep survey via the streak cameras AGAT "SF-3M" and Cordin-173, and photoelectron coaxial diode (PEC) PEC-22SPYM; integral spectrum registration and its continuous sweep survey via the spectrograph MS 257 and the streak camera Cordin-173.

Subnanosecond voltage pulse rise, electric field radial strength at the microconductors surface high values ($E_r = 24$ MV/cm for the microwire with $d = 20$ μm for the open-ended line) and strong non-uniformity of the line, resulting from the huge difference between the diameters of the central core and conductor in respect to the vacuum chamber diameter – are peculiar properties of our experiments. It is shown that microconductors destruction via the EMP with $\tau_f < 1$ ns is caused by the electrodynamic processes, arising within their surface layer and its vicinity. The existence of the pressures range ($0.7 < P < 3.4$ Torr for Cu microwires with $d = 20$ μm) where microconductors either do not destruct or are destructed via thermo-mechanical strains is revealed. At $P > 3.4$ Torr the plasma channel, resulting from the pulse corona discharge, is generated around the microwire and interacts with it, thus leading to its destruction. At $P \leq 3.4$ Torr microwires destruct due to the metal skin layer "electrodynamic explosion". The discharge channel has a complex structure: plasma crown, dense core – non-ideal plasma and a transitional layer in between, where vortex and helical structures, clear luminous spots and plasma jets are observed. Plasma channel emission spectral characteristics are investigated. It has is shown that the emission spectrum at the moment of plasma crown formation is continuous. The most intense Cu spectral lines (510.554, 515.324, 521.82) nm, arise just about ~3 ns after the plasma crown was formed. Using the spectral lines intensities ratio was acquired the electron temperature evaluation: $T_e \sim 0.7$ eV.

The work is carried out under the partial financial support of the RFBR (project No. 10-08-00691-a) and the Presidium of the Ural Branch of Russian Academy of Science within the integration projects, carried out by joint efforts of UB, SB and FEB of RAS (project No. 09-C-2-1002), and also within the Program for basic research of the Presidium of Russian Academy of Science "Thermal physics and mechanics of extreme energetic interactions and physics of strongly compressed matter" (project No. 09-П-2-1016).

Nanocatalysis

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Term "nanocatalysis"[1, 2, 3] corresponds to processes with a cluster as a catalyst. A specific catalyst consisting of 10-20 gold atoms with semiconductors Fe_2O_3, MgO, TiO_2, CeO_2 as supports has the greatest interest. This catalyst may be in the form of micron particles, macroscopic systems and films. This catalyst provides some oxidant processes at room temperature that cannot be attained by other methods, and the main of these is CO oxidation at room temperature. This effect was discovered by Japanese scientists [4, 5] in 1987 by extraction of gold particles and clusters from solutions of gold compounds. They show that catalytic action of gold particles takes place if their is is below 1 nm (the Wigner-Seits radius for gold is 0.17 nm), and the optimal cluster size is if a number of cluster atoms is 10 [6, 7, 8].

Along with filters for cars which can justify a heightened interest to this catalyst, it is used as a sensor of CO [9], and also for control of CO emission from the automobile motor and for air purification [10]. This catalyst is the basis of batteries and methane fuel cells [11].

In considering the chemical process involving the molecule CO and oxygen atom attached on the catalyst surface, we use rich information in experimental study of this process [12] and the experience [13] in research of phase transitions in metal clusters. Representing the process of CO oxidation as a competition of the chemical process with the activation energy of 0.5 eV, and unactivated process which probability is below 10^{-10}, we find that the latter has the character of a tunnel electron transition. Various types of tunnel electron transitions are analyzed.

Список литературы

[1] *Nanocatalysis.* Ed.A.Heiz, U.Landman (Springer, Heidelberg, 2007)

[2] A.Z.Moshfegh. *Nanoparticle catalysis. J.Phys.* **42D**, 233001(2009)

[3] A.J.Gellman, N.Shukla. *Nature Materials* **8**, 87(2009)

[4] M.Haruta. *Catal.Today* **36**, 153(1987)

[5] M.Haruta, T.Kobayashi, H.Sato, N.Yamada. *Chem.Lett.* **2**, 405(1987)

[6] M.Haruta. *The Chemical Record* **3**, 75 (2003)

[7] C.M.Chang, M.Y.Chou. *Phys.Rev.Lett.* **93**, 133401(2004).

[8] A.A.Herzig, C.J.Kiely, A.F.Carley e.a. *Science* **321**, 1331(2008)

[9] N.Funasaki, A.Henmi, S.Ito e.a. *Sensors and Actuators.* **13-14B**, 536(1993)

[10] C.W.Corti, R.J.Holliday, D.V.Thompson. *Phys.Rev.Lett.* **95** 06102(2005)

[11] P.C.Biswas, Y.Nodasaka, M.Enyo, M.Haruta. *J.Electroanal. Chem.* **381** 167(1995)

[12] G.C.Bond, C.Louis, D.T.Thompson. *Catalysis by Gold.* (World Scientific, Singapore, 2006)

[13] B.M.Smirnov, R.S.Berry. *Phase Transitions in Simple Atomic Systems.* (Springer, Heidelberg, 2007).

Generalized Beth-Uhlenbeck equation of state for the nonideal quark plasma

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A microscopic decription of the equation of state for dense hadronic matter including the phase transition to quark matter is a long standing problem relevant for cosmology, heavy-ion collisions and the astrophysics of compact stars and supernovae.
Traditional approaches construct a phase transition from separately given models for hadronic and quark matter phases. They cannot be trusted in the phase transition region and fail to predict a critical point (CP) in the QCD phase diagram.
Functional renormalization group approaches based on effective chiral Lagrangians improve the situation substantially but are not yet developed to describe hadrons as composite particles and thus cannot address the effects of bound state dissociation, such as the role of continuum correlations in the vicinity of the phase transition.
We report recent progress in deriving and solving a generalized Beth-Uhlenbeck equation of state for quark matter with mesonic and baryonic correlations that does not suffer from these problems.
We thus provide a theoretical framework for developing experimental strategies to find the CP of QCD matter in current and future experiments with energy scan programs: STAR@RHIC, NA61@CERN, CBM@FAIR and NICA@JINR.

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Ultracold nonequilibrium plasma in a uniform magnetic field.

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Ultracold plasma is a nonequilibrium plasma, obtained at very low electron temperatures Te~1K within laser ionization of ultracold gas at T<10^{-4}K. Studying of such plasma properties' by the method of molecular dynamics [1-3] revealed that the temperature dependence of collisional recombination coefficient in the region of strong nonideality, when coupling parameter $\gamma \geq 1$ (where $\gamma = e^2 n_e^{1/3} / T_e^{1/3}$, e is electron charge, and n_e is electron density) varies from $T_e^{-9/2}$ to T_e^{-2}.That indicates that the recombination process in the strongly interacting plasma is slower than in weak coupled one.

It follows from the various experimental results, that presence of magnetic field is also affects the collisional recombination process. Moreover, in case of ultracold plasma value of magnetic induction, which can affect the process significantly, estimated as 10^3 G, which is achievable under normal laboratory conditions.

In the presence of magnetic field, except for the Debye radius and Landau length, the plasma is characterized by the electrons Larmor radius, which is associated with cyclotron frequency.

These three length parameters, the cyclotron frequency and electron's de Broglie wavelength identify areas of classical and quantum description of particles motion in plasma, as well as the area of the magnetic field influence on the collisional and recombination processes.

We proposed a new expression for the collisional recombination coefficient in ultracold plasma for the case, when Larmor radius is much smaller than Landau length in the area of classical description of charged particles motion. This expression was obtained by analogy with the Thomson formula. A good agreement with experimental data on recombination of antihydrogen plasma is observed [4].

To study the effect of the magnetic field on collision and recombination processes over the entire range of magnetic induction values in the classical area, the method of molecular dynamics calculations were carried out. We use the model of ultracold plasma, similar to [1-3], but with the influence of magnetic field in motion equations for the particle. We present a distribution functions, diffusion coefficient over energy space, electron velocity autocorrelator and the recombination coefficient at $\gamma \leq 0{,}5$.

References

1. B.B. Zelener, B.V. Zelener, E.A. Manykin, JETP Lett. 92, p. 696 (2010)
2. A.A. Bobrov, S.J. Bronin, B.B. Zelener et al., JETP 139-3, 605 (2011)
3. S.J. Bronin, B.B. Zelener, B.V. Zelener et al., JETP 139-4, 822 (2011)
4. M.Amoretti, et al., ATHENA Collaboration, Nature (London), 456 (2002);G.Gabrielse, et al., ATRAP Collaboration, Phys.Rev.Lett., 213401 (2002);G.B. Andresen, et al., ALPHA Collaboration, Nature Physics (2011), doi:10.1038/nphys 2025, published online 05 June 2011.

The Improved Raizer Method for Plasma Composition Calculations

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Raizer suggested a simple algorithm for the calculation of the composition for the plasma of one element. The method gives satisfactory results until ionization proceeds in the limits of one electron shell. Upon going from one shell to another, the method error essentially increases and becomes tremendous for weak ionization. In addition, the method was not generalized for a mixture of elements.

We suggested improvement of the Raizer method, which increases its accuracy to satisfactory over the entire range of temperatures and densities; this improvement can be generalized to a mixture of any number of elements. The laboriousness of the improved method is the same as that of the startingone. Therefore, it can be used for writing the subroutines involved instead of the tables into gassdynamic computations.

COMPRESSION ISENTROPE OF DEUTERIUM BY QUANTUM MOLECULAR DYNAMICS

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In this work we present our calculations of the compression isentrope of deuterium. We use a pseudopotential density-functional-theory (DFT) code VASP [1] with the plane augmented-wave pseudopotential and generalized-gradient-approximation exchange-correlation functional. The quantum molecular dynamics approach which is based upon the Born-Oppenheimer approximation is applied to calculate pressure and internal energy of dense deuterium plasma. The calculations were made in the range of temperatures 293–25000 K and densities 0.9–4.3 g/cm^3. We use Zeldovich's approach to restore the isentrope and compare the results with experimental data [2] and other theories. The position of the calculated isentrope slightly depends on the initial point but agrees with the initial part and the highest-pressure point (18 Mbar) of the experimental isentrope. However, we didn't find the density jump registered experimentally [2].

1. G. Kresse, J. Hafner, Phys. Rev. B. 1993, 47, 558; Ibid. 1994, 49 , 14251.
2. V. E. Fortov et al. , Phys. Rev. Lett., 2007, 99 , 185001.

NUMERICAL EXPERIMENT FOR the IMPACT IGNITION in the INERTIAL THERMONUCLEAR FUSION.

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At present the acceleration of some mass part of the target up to $10^3 km/s$ velocities are received in the experimental researches [1, 2]. The effective kinetic energy conversion to the specific internal energy during deceleration permits to attain the thermonuclear temperatures and creates the conditions for active passing of the thermonuclear fusion reactions.

Physical model, taking into account: i) the. hydrodynamic motion of high temperature plasma (the laws of mass, momentum, energy conservation) for entirely ionized CD matter of the target; ii) the classical electron heat conductivity with the correction on the degeneracy effects; iii) the electron-ion relaxation;
iiii) the back bremsstrahlung absorption from the laser are used in axially symmetric numerical experiment.

Target consists of the solid sphere with $200 g/cm^3$ density on which the conic cavity filled by the low density matter at some distance was put. The segment was irradiated from the laser with flux density $8,36 \cdot 10^{13} wt/cm^2$ and the total energy 500 J on external side.

Acceleration of the segment part up to the few hundreds km/s velocities and collision with the solid sphere, the spatial and temporal thermonuclear neutrons generation distribution, the laser irradiated energy transformation to the accelerated segment energy, to the conic cavity wall energy, to scattering plasma energy was obtained in the numerical computations.

References:

1.M.Murakami, H.Nagatomo " A new twist for inertial fusion energy: Impact ignition", Nucl.Inst&Meth.Phys.Res. A544, pp.67-75 (2005).

2.S.Yu.Gus'kov,H.Azechi, N.N.Demchenko, V.V.Demchenko et al. "Laser-driven acceleration of a dense matter up to "thermonuclear" velocities", Plasma Physics And Controlled Fusion, 49 (2007), pp.1689-1706.

EXPERIMENTAL DETERMINATION OF DESTRUCTION TIME FOR POLYMETHYLMETHACRYLATE AND POLYSTYRENE BEHIND THE SHOCK FRONT INITIATED BY HIGH-CURRENT ELECTRON BEAM PULSE

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We studied the behavior of polymethylmethacrylate and polystyrene which exposed to high-current electron beam pulse. It was defined the time of material destruction by the shock wave initiated electron beam pulse. These data were obtained experimentally using shadow optical streak-camera picture; the shadow was constructed by the probing laser. It is shown that failure occurs during the unloading of the material, but not in the shock front. It is established that, despite the different nature of the destruction of the polymers in close vicinity of the irradiated surfaces, the velocity of the destruction wave are close.

DUST PARTICLE SHIELDING WITHIN THE NONLOCAL CHARGING MODEL

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In the present paper the effects of non-locality of the electron energy distribution function (EEDF) on dust particle potential dependence in a two-component plasma of different noble gases and nitrogen at atmospheric pressure were studied. The plasma was generated by an external ionization source, with the ionization rate varied from 10^{12} to 10^{18} $cm^{-3}s^{-1}$. The point sink model in the diffusion-drift approximation including the electron and ion absorption by a microparticle was chosen for analytical and numerical calculations. The EEDF non-locality was taken into account by an additional electron energy balance equation which related the mean electron energy at some point with plasma parameters in the neighbor points. It was found that in that case the dust particle potential distribution was described by the superposition of three Debye exponentials with three different screening constants. The first constant was practically equal to the inverse Debye radius, the second one was defined by the inverse length of the ambipolar diffusion of electrons and ions at the characteristic recombination time. The third constant was coincident with the inverse characteristic length of the electron energy transfer at the characteristic time of the electron energy relaxation in heating processes by a fast electron beam and energy losses in elastic and inelastic collisions.

EXPERIMENTAL DECAY COEFFICIENT AND THE LIFETIME CHARGED PARTICLES TO BE COMPARED WITH CALCULATION

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In work [1-3] was shown that the decay factors (Kr) obtained in nonideal plasma (NP) of the pulsed discharge in water (PDV) is on several orders lower that calculated on formula for thick hydrogen plasma, opaque for the Lyman series radiation line [4]. Plasma ionization was also taken into account [4] and recombination was considered triple. The comparison K_r with accounting on formula for NP [5] also gives lower value in comparison with experimental result on several orders. It was considered that nature recombination processes in NP are binary and was considered approach of the nearest neighbour and cell model [5]. The coulomb logarithm changes were also taken into account under greater electron concentration [6]. But experimental value K_r was found much below theoretical. The results of K_r experimental measurements become greatly approach to theoretical [4, 5] only at reduction of electron concentration up to value 10^{17} sm^{-3} and less. The results of H_α approximation begins to reveal with consequent appearance in spectrum of the radiation the hydrogen line H_α (656,3 nm), H_β (486,1 nm), H_γ (434,047 nm) and others [7]. This is indicative that recombination goes not only on the hydrogen atom main level. But essential contribution to recombination make by more high level atoms [8], which begin to appear in radiation spectrum with reduction of the electron concentrations [7].

It was maked comparison of experimental value Kr with theoretical in [9]. The changes K_r on three orders observe experimentally with increase nonideal degree G from 0,1up to 0,3. Under the further increase nonideal degree G value, K_r increase on order passing the maximum and with increase G from 2 up to 4.5 it is observed the fluent reduction the decay factor on order. These results qualitative comply with theoretical results [9] though quantitative there is divergences. Under $G < 1$ experimental value K_r on two orders below accounting, but under $G = 4$ they coincide. Increases G lead to fact, that theoretical value of the recombinations velocity, calculated on [9], become less, than experimental data. From decay factor we can get the average electron lifetime and ion ($\tau_ж$) in plasma. Comparison of the experimental lifetime with theoretical lifetime, calculated on the work [4, 5, 9] was conducted.

1. O.A. Fedorovich, L.M. Voitenko. Experimental Researches of the Decay Coefficient of Nonideal Plasma Produced at Pulsed Discharges in Water // Ukrainian Journal of Physics. 2008, v. 53, N 5, p. 450-457.
2. О.А. Федорович, Л.М. Войтенко. О коэффициентах распада НП при взрыве вольфрамового проводника в воде // ВАНТ, сер. «Плазменная электроника и новые методы ускорения», вып.7 №4(68), 2010.
3. O.A. Fedorovich, L.M. Voitenko The empirical formula of dependence of factor of disintegration of nonideal plasma from electrons concentration // Problems of atomic science and Technology, №1 (71), 2011, p. 122-124
4. L.C. Johnson, E Hinnov. Ionization, recombination and populazion of excited levels in hydrogen plamas // J. Quant. Spectrosc. And Radiat. Transfer., 1973, vol. 13, p. 333
5. Биберман Л.М., Воробьев В.С., Якубов И.Т. Коэффициент рекомбинации в НП //ДАН, 1987. Т.296. №33, с. 576-578.
6. Р.В. Митин, В.П.Канцедал, Г.П.Глазунов. Экспериментальное определение электропроводности плотной плазмы при малых значениях кулоновского логарифма // Теплофизика высоких температур, 1975, том 13, №4, с. 706-711
7. О.А. Федорович, Л.М. Войтенко. Экспериментальные исследования коэффициентов распада неидеальной плазмы при концентрациях электронов не превышающих 10^{22} $см^{-3}$ // Материалы XV международной научной конференции ФИРКС, Николаев, 2011, с. 66-69
8. Ю.К. Куриленков. О влиянии неидеальности на коэффициент рекомбинации плотной плазмы // ТВТ, 1980, 18, №6, с. 1312-1314
9. A. Lankin, G. Norman. Density and nonideality effects in plasmas // Contribution to Plasma Physics, 49, №10, 2009.p. 723-731

NONEQUILIBRIUM RADIATION THE PULSED DISCHARGE IN WATER TO VISIBLE RANGE AND IT DEPENDENCE FROM ELECTRIC FIELD STRENGTH

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One of the most important sources of the information about the plasma parameter in channel of the pulsed discharge in water (PDW) is his radiation. In [1,2] was shown that radiation from channel PDW is a nonequilibrium, but measured on various wavelength the brightness temperature of the plasma channel can greatly differ. The degree of nonequilibrium depends on initial conditions in discharge. In [3] is shown that the nonideal plasma radiation (NP) got on magnet plasma compressor of the erosion type is also nonequilibrium but degree of the departure from equilibrium radiations increases with growth of the electric field strength. This is connected with appearance ultra speed electrons, leading to increasing of the intensities of the radiation with greater energy quantum [4].

In work [2, 5] nonequilibrium radiations NP of PDW was explained by influence the temperature gradient of the external layers in plasma channel and leaving the short-wave radiation from greater depths of the plasma, where temperature above than in externally layer. But this explanation contradicts to that the most intensive line of the hydrogen does not exist on initial stage of the discharge Balmera series H_α (656,3 nm) (even in absorption). The nonuniformity parameter of the hydrogen plasma, according to [6], for line H_α is equal 0,95 (but for continuous spectrum it equal 0,91 on λ =600 nm). Therefore the nonuniformity plasma channel influence on hydrogen plasma radiation intensity must be low. But difference in brightness temperature, measured on wavelength 400 and 700 nm can differ twice [2], particularly under greater velocity of the introduction entering to energy in channel PDW.

In given work the results of the influence of the electric radiation parameter of the plasma channel on the nonequilibrium radiations of NP are shown. It is shown that although the radiation intensities fluctuation of the plasma channel does not correlate with contribution of the powers in channel, the degree of nonequilibrium value $\frac{\Delta T}{\Delta \lambda}$ correlate with fluctuations of the powers. The nonequilibrium degree practically always complies with the first maximum of the current. The maximum value of nonequilibrium dependence from the initial electric field strength in discharge, from the electric field strength in first maximum of the current, from the discharge gap length for initial voltage constant on battery. The possible mechanisms of the observed effect are discussed.

1. Martin E. Experimental Investigation of a High-energi Densiti High-pressure Arc Plasma // J. Appl. Phys.–1960, V31, N2, p. 255-254.
2. Пасечник Л.Л., Старчик П.Д., Федорович О.А. Исследование непрерывного излучения ИРВ в диапазоне 400-700 нм // Тезисы докладов VI Всесоюзной конференции по физике низкотемпературной плазмы – т.1. Ленинград. 1983, С. 501-503
3. Kozlov N.P., Norman G.E., Protasov Y.S. Superradiation from non-ideal plasmas in electric field // Phys. Letters.–1980, 77A, N6, p. 445-447.
4. Козлов Н.П., Протасов Ю.С. О механизме генерации быстрых частиц и коротковолнового излучения в сильноточных плазмодинамических разрядах магнито-плазменного компрессора // Письма в ЖТФ. – 1981, 7, вып. 16, С. 1036-1041.
5. Войтенко Л.М., Кононов А.В., Порицкий П.В., Старчик П.Д. Оптическое излучение импульсных электрических разрядов в воде // Матер. 13 Межд. Научной школы-семинара «ФИРКС 2007». Николаев. 2007. С. 14.
6. Методы исследования плазмы. Под ред. В. Лохте–Хольтгревена.–Мир 1971. - 552 с.

Quantum Monte Carlo simulations of strongly coupled quark-gluon plasma

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In recent years, there has been an increasing interest in dynamics and thermodynamics of non-Abelian plasmas at both very high temperature and density. It is expected that a specific state of matter with unconfined quarks and gluons - the so called quark - gluon plasma (QGP) - can exist. The most fundamental way to compute properties of the strongly interacting matter is provided by the lattice QCD. Interpretation of these very complicated computations requires application of various QCD motivated, albeit schematic, models simulating various aspects of the full theory. Moreover, such models are needed in cases when the lattice QCD fails, e.g. at large baryon chemical potentials and out of equilibrium. A semi-classical approximation, based on a point like quasi-particle picture has been recently introduced in literature. It is expected that it allows to treat soft processes in the QGP which are not accessible by the perturbative means and the main features of non-Abelian plasmas can be understood in simple semi-classical terms without the difficulties inherent to a full quantum field theoretical analysis.

Here we propose stochastic simulation of thermodynamics and kinetic properties for QGP in semi-classical approximation in the wide region of temperature, density and quasi-particles masses. We extend previous classical nonrelativistic simulations based on a color Coulomb interaction to the quantum regime and take into account the relativistic effects as well as Fermi (Bose) statistics of quarks (gluons) and quantum degeneracy self-consistently.

In grand canonical ensemble for finite and zero baryon chemical potential we use the direct quantum path integral Monte Carlo method (PIMC) developed for finite temperature within Feynman formulation of quantum mechanics to do calculations of internal energy, pressure and pair correlation functions. The QGP quasi-particles representing dressed quarks, antiquarks and gluons interact via color quantum Kelbg pseudopotential rigorously derived in for Coulomb particles. This method has been successfully applied to strongly coupled electrodynamic plasmas (EMP) . A strongly correlated behavior of the QGP is expected to show up in long-ranged spatial correlations of quarks and gluons which, in fact, may give rise to liquid-like and, possibly, solid-like structures. This expectation is based on a very similar behavior observed in electrodynamic plasmas.

We have done already the first calculation of the QGP equation of state, spatial and color pair distribution functions, diffusion coefficients and shear viscosity.

EQUATION OF STATE OF SHOCK COMPRESSED GASES AT MEGABAR PRESSURE RANGE

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Model for equation of state of warm dense matter based on chemical picture was used for calculation of principal Hugoniots of hydrogen deuterium and helium, calculation of thermodynamics for reshock states and third-shock reverberation of deuterium and isentropically compressed helium. Coulomb interaction of charged particles, short-range repulsion and attraction of heavy particles and partial degeneracy of free electrons was taken into account. The calculation results were compared with gas-gun, explosive, magnetically launched flyer-plate, laser experiments and with the results of the first-principle modeling.

High Energy Density Physics with intense Heavy Ion Beams

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It is expected that the future heavy ion facility, FAIR (Facility for Antiprotons and Ion Research) will provide compressed beam pulses with an intensity that exceed the current beam intensities by three orders of magnitude. This will open up the possibility to explore the thermophysical and transport properties of HED matter in a regime that is very difficult to access using the traditional methods of shock compression.

Currently the most intense heavy ion beam for experiments to induce high energy density states in macroscopic amounts of matter is available at GSI in Darmstadt. Recently a new record intensity was achieved with more than 10**10 Uranium Ions at charge state 73+ and an energy of 350 MeV/u. This allows studying thermophysical properties of high energy density states when matter passes the warm dense matter regime of the phase diagram at high density but relatively low temperature.

We have investigated hot liquid tantalum and tungsten and present measurements of the temperature as function of specific enthalpy. An ongoing project is the development of a non-contact measurement of the electrical conductivity of warm dense matter. The density evolution of warm dense matter will be investigated with a proton microscope, which is under construction at GSI. In this talk we will also summarize the progress on the development of cryogenic targets. Thus the talk will give an overview on recent results and developments of beam plasma, and beam matter interaction processes studied with heavy ion beams.

THERMODYNAMIC STUDY OF NEW EXERIMENTAL DATA ON SHOCK COMPRESSION OF LIQUID NITROGEN IN 1-3 MEGABAR RANGE

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Thermodynamic properties of strongly shock-compressed liquid nitrogen are under discussion. The base for discussion are experimental data, obtained recently in VNIIEF (Sarov) using hemispherical shock wave generators [1,2]. These experiments covered nitrogen Hugoniots in pressure range 100–3500 GPa and temperature range 10–80 kK. Joint analysis of the data of measurement for thermal and caloric EOS-s leads to conclusions about strong constraints, which should be fulfilled by any theoretical model proposed for thermodynamic description of warm dense nitrogen in newly investigated region. A nearly isochoric behavior of nitrogen Hugoniots and quasi-linear behavior of measured temperature indicates existence for significant range in nitrogen plasma of nearly constant Gruneisen parameter, isochoric heat capacity, thermal pressure coefficient and so-called compressibility factor.

New data on thermodynamics of shock-compressed nitrogen are analyzed theoretically using so-called quasi-chemical model (code SAHA-N) where nitrogen plasma is described as strongly interacting (non-ideal) equilibrium mixture of atoms, molecules, ions and electrons. Calculation data obtained via semi-empirical EOS, developed in VNIIEF [2], are also used for comparison. This approaches supplement in the high-*P*_high-*T* region previous calculations of shock-compressed nitrogen of moderate parameters ($P < 100$ GPa) as series of molecular and polymeric states. Presently discussed experimental data combined with theoretical calculations lead to conclusion that approximately at $P \approx 100$ GPa, $T \approx 16000$ K, and $\rho \approx 3.3$ g/cm^3 shock-compressed nitrogen comes through new type of “pressure ionization” – not from molecular (like hydrogen) but from polymeric state to the state of strongly non-ideal plasma.

[1] M.A. Mochalov, M.V. Zhernokletov, R.I. Il'kaev, A.L. Mikhailov, V.E. Fortov, V.K. Gryaznov, I.L. Iosilevskiy, A.B. Mezhevov, A.E. Kovalev, S.I. Kirshanov, Yu.A. Grigorieva, M.G. Novikov, A.N. Shuikin, *JETP,* **137**, 77 (2010)
[2] R.F. Trunin, G.V. Boriskov, A.I. Bykov, A.B. Medvedev, G.V. Simakov, and A.N. Shuikin, *JETP Lett.* **88**, 189 (2008)

Diffusion in ionic liquids. Classical molecular dynamic study

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Ionic liquids are usually organic salts with melting temperatures below 100°C. Irregular shape of ions results in lower binding energy in the crystalline state and lower melting temperature. Their organic nature makes it possible to adjust smoothly the properties of ionic liquid for a specific application.

Ionic liquids are used as electrolytes in supercapacitors and batteries. Along with high energy capacity comparable with energy densities of electrochemical cells supercapacitors possess short charging/discharging times as those of convenient capacitors. In addition, the supercapacitor practically does not degrade during charging/discharging cycle.

Usage of ionic liquids as electrolytes for supercapacitors produces a series of research problems. Particularly, diffusive and viscous properties of ionic liquids in porous structure of the supercapacitor electrode have to be studied, because these are the factors defining charge/discharge times of the device. Systems with both ionic liquid and electrode are very difficult to describe and are to be studied using quantum approaches. In this work we apply methods of classical molecular dynamics to study diffusive characteristics of the system composed entirely of the ionic liquid.

Two types of ionic liquids were studied: 1-buthyl-3-methylimidasolium tetrafluoroborate ($[bmim]^+[BF_4]^-$) and N-methyl-N,N,N-triethylammonium tetrafluoroborate ($[tema]^+[BF_4]^-$). Data were obtained showing not typical time dependence of the mean square displacement of the centers of mass of the ions. Quite long transition between ballistic regime and diffusion obeying Einstein−Smoluchowski relation was observed. Special attention was paid to the problem of the statistical error of the molecular dynamic simulation results quantification.

“Dielectric catastrophe” and insulator-conductor transition

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Phenomenological conception of “dielectric catastrophe” applies to explanation of dielectric-conductor transitions in metal hydrides, hydrogen, rare gases and alkali metals. This conception together with simple cell model appears to be applicable for the metal hydrides, where it predicts the correct transition density. For the others substances it fails, but the cell model are still of use in description of metallization and dielectrization at extremely high pressures.

Metallization of an atomic gas and the vapor-liquid transition in alkali metals vapor.

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Metallization of an atomic gas is the process of delocalization of electrons in the ground state at atomic gas compression. The physical conditions of metallization are caused by appearance of Bloch electrons and increase of the ground state energy (an electronic term) of system of atoms.

The bases of the theory of an atomic gas metallization are made in works of Wigner-Seitz and J. Bardeen. The result of this theory is the calculation of collective quantum binding energy (cohesive energy), compressibility and so on for liquid alkali metals. When the mean interparticle distance is compared to particle diameter the effects of metallization are appeared. Hence, traditional, pair additive description of interparticle interaction with use of central symmetric potentials, does not work.

In the present study, the physical model of alkali metals vapor taking into account effects of metallization of an atomic component is under construction. The concept of cohesive energy is extended to gaseous state. Within the framework of the unified approach the model described gaseous and liquid-metal phases, including vapor-liquid transition. The model explicates the model of gaseous metals of Likalter.

Difficulties of application of Wigner-Seitz-Bardeen theory to liquid alkali metals are connected with necessity of the account of the ionic core. Numerical simulation and various extrapolation approaches, for example a quantum defect method, are used. In the present study, we offered the Kratzer potential to use as interatomic potential of alkaline atoms. Kratzer potential successfully used earlier for the description of the ionic molecules. By analogy to Lenard-Jones potential it is possible to term it as (2-1) potential. On long distances it has a Coulomb asymptotic, and on short distances contains the repulsion that modeling the ionic core. The Schrodinger equation with the Kratzer potential has the exact solution that allow to define a factor of repulsive term, having equated the energy of a ground state of an isolated atom analytically founded to the experimentally measured one.

Cohesive energy is calculated for alkali metals in whole range of Wigner-Seitz cell sizes using the theory of Wigner-Seitz-Bardeen for the ordered system of atoms with interatomic Kratzer potential. This energy has two extremum: a minimum at liquid-metal densities and a small maximum at lower one. It’s occurs when the radius of a classical orbit of the bound electron is equal to radius of Wigner-Seitz cell, passed through a zero between them. The density at which binding energy vanished is close to the critical one.

The thermodynamics of vapors calculated using the thermodynamic perturbation theory for a one-component system taking into account excluded volume and the metalized binding energy of atoms. The model contains vapor-liquid phase transition (Van der Waals loop) which parameters will qualitatively agree with known values. Conductivity is calculated with use of Joffe formula. Conductivity at near critical temperatures shows metal-dielectric transition. Correlation of this transition and with vapor-liquid transition is considered.

In our opinion, our approach for the account of metallization effects ("ionization" by pressure) of an atomic gas opened interesting perspective for the further development of thermodynamic models of the dense gases and fluids.

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Impact of nonideality and dissipation on thermal conductivity of dust in plasma

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Dissipative 2D nonideal system of interacting particles near equilibrium is concerned and referred to as model for dusty component of complex plasmas. The repulsive isotropic pair potential is written:

$$\phi(r)=\frac{(Ze)^2}{r}\exp(-r/\lambda) \quad .$$

Here Ze is a macroparticle charge, and λ is the screening length. The Green-Kubo relation s used to calculate the value of thermal conductivity χ :

$$\chi=\frac{n}{sT^2}\int_0^\infty \langle \delta\mathbf{j}_Q(0)\delta\mathbf{j}_Q(t)\rangle dt \quad .$$

Here s is the number of dimensions, n denotes concentration, and T is for temperature. The $\delta\mathbf{j}_Q$ is the fluctuation of heat flux which is developed as:

$$\mathbf{j}_Q(t)=\frac{1}{2}\mathbf{V}MV^2+\frac{1}{2}\mathbf{V}\sum_{j\in\mathrm{Sur}}\phi(\Delta r_j)-\frac{s}{4}\sum_{j\in\mathrm{Sur}}\left(\Delta\vec{r}_j\vec{V}\right)\phi'(\Delta r_j)\frac{\Delta\mathbf{r}_j}{\Delta r_j} \quad .$$

Here M is a macroparticle mass, $\mathbf{V}$ its velocity. The summation over index *j* is performed throughout particles which influence the chosen particle via interaction potential.

The value of thermal conductivity is determined by two dimensionless parameters (Γ^* and ξ). With decrease of the parameter $\Gamma^* < 2$ the ratio of kinetic part of kinetic thermal conductivity χ_K to diffusion coefficient D tends to the value close to heat capacity at constant pressure $C_P \sim 2$. For weakly correlated systems which are most commonly observed in laboratory experiments at low values of the parameter Γ^* the kinetic part of thermal conductivity χ_K tends to the entire thermal conductivity χ.

Energy conduction (to be more specific the conduction of kinetic energy and the thermal part of potential energy) is inversely proportional to dissipation coefficient $\nu_{dis} \equiv \omega^* + \nu_{fr}$. As for the conduction of “external” potential energy which corresponds to the inner pressure in the system is independent of friction ν_{fr} and appears to be constant at all $\Gamma^* > 10$.

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Experimental evidence of the first order metal-to-nonmetal phase transition with 5 GPa critical pressure in fluid iron

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Simultaneous measurements of electrical resistivity and caloric equation of state have been performed for fluid iron in the warm dense matter regime to investigate the metal-to-nonmetal transition induced by thermal expansion. The resistivity results published earlier [1] have shown the transition occurs at densities 2 to 5 times lower than ambient solid since in this density range the isochoric temperature coefficient of resistivity changes sign from positive to negative and the magnitude of resistivity is near the minimum metallic conductivity range. The equation of state results reported here provide an evidence for a first order phase transition with a critical point located in this density range [2]. The phase transition is clearly detected by kinks in isochores plotted in the pressure – internal energy plane and in isentropes in the pressure-specific volume plane. Arguments are presented that the phase transition is the discontinuous Mott transition has not been observed previously.

1. V. N. Korobenko and A. D. Rakhel, JETP, 112, 649 (2011).
2. V.N. Korobenko, A.D. Rakhel, arXiv:1101.0487v2 (2011).

Thermodynamic properties of binary Coulomb crystals

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Thermodynamic functions of a Coulomb crystal composed of two types of ions with a uniform electron background are studied using harmonic lattice approximation. We consider two types of lattices: simple cubic lattice with two ions per elementary cell (scb) and hexagonal close packed lattice (hcp). An analysis of the phonon spectra shows that these binary Coulomb crystals are stable, if the ratio $\alpha = Z_2/Z_1$ is not too large: $\alpha \in [1, 3.6]$ for the scb lattice and $\alpha \in [1, 1.274]$ for the hcp lattice (here Z_i is i-th ion charge number; ion numbers 1 and 2 are chosen so that α>1). The stability criterion does not depend on ion masses. Quantum and classic asymptotes of the thermodynamic functions are analyzed.

PARTICULARITIES OF PROPERTIES OF MATTER IN THE FIELD OF NEGATIVE PRESSURES CREATED BY MEANS OF PICOSECOND LASER PULSE

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The experimental studies of dynamic mechanical durability of aluminum, alloy AMг6M and polymethylmethacrilat at the influence on them of laser pulse with duration 70 ps are presented. In preceding experiences of authors duration of laser pulse was 2.5 ns. Using of more short pulses has allowed to realize in this study of strain rate above 10^7 1/s. Results of experiments have shown that, when increasing a strain rate spall strength of matter under investigation tend to their essential reducing with respect to the theoretical limit of toughness. It was established that behavior of matter in the field of negative pressures when using the laser influence depends in big degrees from history of dynamic pressure, comprising of itself much factors, amongst which vital importance has both amplitude, and shock wave pulse duration influencing on target.

FIRST-PRINCIPLES CALCULATIONS OF PHYSICAL PROPERTIES OF CONDENSED SYSTEMS AT HIGH PRESSURES

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We report on theoretical studies of highly compressed substances in which high pressures/temperatures are either (i) external parameters affecting the properties of systems under study or (ii) conditions for obtaining new metastable phases.

i) The dynamical structure factor $S(\mathbf{q}, \omega)$ of metallic sodium in the bcc and fcc phases is calculated in the range of pressures from 65 to 100 GPa and temperatures from 250 to 700 K. The study is conducted using the first-principles quantum molecular-dynamics simulation, i.e. with anharmonic effects fully taken into account. The phonon dispersions $\omega(\mathbf{q})$ found as the positions of the peaks of $S(\mathbf{q}, \omega)$ are in good agreement with our previous calculation within quasiharmonic approximation. This implies that the anharmonism does not significantly affect the lattice dynamics of Na up to the temperatures near the melting curve.

ii) *Ab initio* density-functional calculations are performed of new compounds CrGaSb и $CrGa_2Sb_2$ recently synthesized under high pressure/temperature conditions. Experimentally, the metastable phase $CrGa_2Sb_2$ is a ferromagnet with the high Curie temperature ($T_C \sim 350$ K) and possesses a very high electrical resistivity, which might be an evidence of semiconducting behavior. The calculated magnetic and optical properties of $CrGa_2Sb_2$ well agree with available experimental data, however our calculations characterize this compound as a poor metal with a ‘pseudogap’ feature near the Fermi level. At the same time, the shape of the band structure implies that under certain conditions, half-metallic phases may form in the system Cr–GaSb, which makes this system interesting for spintronics.

Warm dense matter generation and DD synthesis at vacuum discharge with deuterium-loaded Pd anode.

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The energetic ions and DD neutrons from microfusion at the interelectrode space of a low energy nanosecond vacuum discharge has been demonstrated recently. To understand better the physics of fusion processes the detailed PIC simulation of the discharge experimental conditions have been developed using a fully electrodynamic code. The dynamics of all charge particles was reconstructed in time and anode cathode (AC) space. The principal role of a virtual cathode (VC) and the corresponding single and double potential well formed in the inter-electrode space are recognised. The calculated depth of the quasi-stationary potential well (PW) of the VC is about 50-60 kV, and the D^+ ions being trapped by this well accelerate up to energy values needed to provide collisional DD nuclear synthesis. Both experiment and PIC simulations illustrate very favourable scaling of the fusion power density ($\sim 1/r^4$) at decreasing of VC radius for the chosen inertial electrostatic confinement fusion scheme based on nanosecond vacuum discharge. Meanwhile, the initial stage of discharge is understood still poorly. When voltage is applied, the electron beam extracted from cathode starts to interact with the surface of Pd anode loaded by deuterium. This early stage of discharge manifests sometime the peaks registered by photomultipliers which are similar to neutron ones from time-of-flight measure used under study of collisional DD synthesis at the further stage of discharge. The detailed study of Pd anode surface morphology have been performed and recognized, in particular, the number of various pores and craters of different sizes. We remark that besides of rather usual craters (due to electron beams – anode interaction) some of the craters on the Pd anode surface may correspond to anode ectons (explosive centers) and discuss their possible nature. Specifics of warm dense matter (WDM) generated at different stage of discharge is discussed. The data obtained are compared with recent results on initiation of DD –reactions by electron beams at deuterium loaded Pd samples and correspondent data on their surface morphology.

Abnormal pressure fluctuations and thermodynamic instabilities in classical nonideal plasma.

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The hypothesis of the plasma phase transition (PPT) is advanced in [1 – 2] by analogy with phase transition in the Van der Waals gas. The first order phase transition is a result of the balance between long-range attraction and short-range repulsion. Coulomb interaction between charges is a long-range and effectively attractive one because of the plasma polarization. An effective repulsion at short distances even for an electron-proton pair is of the quantum nature. However contrary to real gases there are excited atoms in low temperature plasmas. The restriction of the discrete spectrum in the atomic partition function depends on the charge number density. It was noted [3 – 4] that this dependence results in the appearance of a new term in the equation of state. The term is equivalent to the effective repulsion. Therefore this factor is able to suppress or influence the PPT.

The chemical plasma model is used in [1 - 4]. We guess that it is more logical to apply the approach [5] which provides the self-consistent joint description of free and weakly bound electron states without their separation. The molecular dynamics method is used. The electron-ion interaction is described by the density and temperature-independent cutoff Coulomb potential. The considered system is at equilibrium state. Fluctuations of pressure and temperature of singly ionized nonideal plasma are studied. Distribution function of temperature fluctuations is normal, which is in accordance with classical theory of thermodynamic fluctuations. Two main abnormal features of pressure fluctuation distribution are observed. (a) The fully ionized plasma region is found where pressure fluctuation distribution dramatically differs from normal distribution and can be approximated by the superposition of two Gauss distribution functions. (b) There is also a region of plasma parameters where negative instantaneous values of pressure are observed. It should be noted that these regions of plasma parameters lay out of the area of the abovementioned stabilized factor action. We also found the region of plasma parameters where pressure does not depend on charge density. Therefore by the analogy with Van der Waals gas the estimation of critical parameters was obtained. The results could be considered as a precursor of the PPT.

References

[1] G.E. Norman, A.N. Starostin, High Temperature **6**, 394 (1968)

[2] G.E. Norman, A.N. Starostin, High Temperature **8**, 413 (1970)

[3] V.K. Gryaznov, I.L. Iosilevskiy, V.E. Fortov, J. Appl. Mech. and Tech. Phys. 3, 70 (1973)

[4] A. S. Kaklyugin, G. E. Norman, *Entsiklopediya Nizkotemperaturnoi Plazmy. Seria B. Tom III-I (ed by V. E. Fortov)* (Fizmatlit, Moscow, 2004)

[5] A.V. Lankin, G.E. Norman, J. Phys. A: Math. and Theor. 42, 214032 (2009)

Dinamic Dust Particle Confinement in Corona Discharge Plasma

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Experimental research of argon-xenon dusty plasma and numerical simulation [1,2] shows the possibility of forming of the ordered dust structures and dust crystals from charged micron uranium and uranium oxide particles. Such dust structures allow to increase efficiency of the direct conversion of nuclear energy into the optical radiation. We are using numerical simulations to investigate the possibility of the forming of the dust structures in dynamic electrical traps such as the Paul trap or quadrupole trap. Numerical simulations of dust particles behaviour for potential forces acting on dust particles is considered, the influence of buffer gas medium is taken into account by viscosity and random forces. In considered model the dust particle motion is described by the Langevin equation:

$$m_d \frac{d^2 r_i}{d^2 t} = F_{tr}(t, r_i) + F_{\text{int}}(r_i) - 6\pi\eta R_d \frac{dr_i}{dt} + F_i^{Br} + F_{mg}$$

where i = 1,…,N_d, N_d – number of dust particles, R_d – dust particle radius, η - dynamic viscosity, $F_{tr}(t,r_i)$=-grad(U_i ,t) – force of external electric field that compensate the gravity force, F_{Br} – stochastic delta correlated forces that describe dust and plasma particles collisions, F_{mg} – dust particle weight, F_{int}(ri)=- grad(U_i) – forces acting between dust particles, U – potential energy of dust particle interaction accounting for the shielding. Detailed description of numerical method is given in [3]. All test of calculations were carried out for one dust particle in harmonic trap $V(x)=\omega x^2/2$. Test results agree very well with analytical solutions.

Obtained results for Paul trap showed the appearance of standing waves of the dust particle density arising due to the dynamic effects of periodic external low frequency electric field. The dependences of electric field amplitude and frequency needed for levitation of dust particles in a quadrupole trap have been studied. The dependence of the equilibrium position of dust structures in a quadrupole trap versus the frequency of the alternating electric field is investigated.

[1] Rykov V.A., Khudyakov A.S., Filinov V.S. and others, Plasma Physics. V.28, No.5, P.1-11. (2002)
[2] Filinov V.S., Naumkin V.N., Vladimirov V.I., Meshakin V.I., Rykov V.A., Influence of Potential and Non Potential Forces of Interparticle Interaction on Stability of Nuclear Excited Dusty Plasma, Contrib. Plasma Phys. V.49, No.7-8, P.446-450 (2009)
[3] Skeel R.D., Izaguirre J.A. An impulse integrator for Langevin dynamics, Molecular Physics. V.100, No.24, P.3885-3891. (2002)

Dusty plasma under microgravity conditions: results of experiments on the International Space Station

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The survey of results of the dusty plasma physics investigations under microgravity conditions with the help of the unique experimental installation "Plasma Crystal-3 Plus" (PK-3 Plus), working on the Russian segment of the International Space Station from January of 2006, is presented. The use of the installation "PK-3 Plus" gives a possibility to obtain new knowledge on the dusty plasma properties. The region free of microparticles, formed in the discharge center, prevents to obtain a homogeneous and isotropic dusty-plasma system. In the case of "PK-3 Plus" it is possible to close the central region by 3 procedures: 1) by decreasing a power of the high frequency discharge up to possible minimum values; 2) using the symmetrical gas flow; 3) by an action of the external low frequency electric field. The last procedure was used to perform a phase transition from the isotropic liquid dusty-plasma system to the so-called electrorheological plasma. The transition is the isotropic one and is fully reversible. The other interesting phenomenon is an interpenetration of two clouds of microparticles of different sizes. In these experiments we formed initially a structure consisting of particles with diameters of 14.9, 9.19 and 6.8 microns. Then dust grains of a smaller diameter are injected into the formed structure. When a velocity of the penetrating particles is rather high the lane formation has been observed. This phenomenon is the non-equilibrium transition, depends upon peculiarities and dynamics of the particles interaction and is of interest for different physics fields. The experimental installation "PK-3 Plus" allows us to investigate the transition liquid-crystal in the large (more than million highly charged dust particles) three-dimensional dusty-plasma system. The dusty plasma system crystallizes when a gas pressure is decreasing. At the following pressure increase a melting of the dusty-plasma system takes place. The observed behavior of the large three-dimensional dusty-plasma system is quite opposite to a behavior of two-dimensional dusty-plasma system. We performed also experiments to discover a crystallization front in the three dimensional dusty plasma.

Simulation of absorption of femtosecond laser pulses in solid-density copper

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We present a simulation of absorption of femtosecond laser pulses by a copper target. The modeling involved thermodynamic functions calculated by using a first-principles full-potential linear muffin-tin orbital method and chemical-picture-based model of dense plasma utilizing a superconfiguration approach. The results of the simulation are compared to experimental and other theoretical data. The role of the electron-ion energy exchange is analyzed and further work on detailed improvement of the presented theoretical model is discussed.

Dust structures in plasmas with high anisotropy of the ion velocity distribution.

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When the field is strong, the ion heating is significant, and there is a large difference in atomic weight between ions and atoms, the ion velocity distribution can be highly anisotropic [1]. Since anisotropy of the ion distribution, in turn, can cause a substantial change in properties of dust structures in plasmas, an experiment was proposed on discharge in a mixture of light and heavy gases by one of this paper co-authors. The mixture parameters of primary importance include ionization energy, atomic weight, and polarizability of atoms. The percentage of different species is also an important factor. These parameters can be adjusted to generate an ion flow with desired characteristics. For example, the addition of a small amount of a heavy gas (e.g., krypton or xenon) or heavy metal vapors to helium would drastically change ion flow characteristics, and the properties of dust structures in the resulting discharge plasma should change accordingly.

The first experimental studies of properties of dust structures in mixtures of two gases, helium and krypton, were conducted in [2]. Characteristic feature of the dusty plasma structures observed was the formation of linear, chain-like dust structures packed parallel to each other and dust kinetic energy increase. The results of simulations performed for a mixture containing a heavy, easily ionized gas (or heavy metal vapors, such as mercury or cesium) suggest a strong effect of gas composition on dust structures in discharge plasmas, making it possible to predict their characteristics due to a supersonic flow regime (Mach cone, anisotropy of interaction between dust grains, etc.).

References.

1. S.A. Maiorov// Plasma Phys Reports, **35**, 802 (2009).
2. S.N. Antipov, M.M. Vasiliev, S.A. Maiorov, O.F. Petrov, and V.E. Fortov// JETP, **112**, 483 (2011).

PROTON RADIOGRAPHY OF NONIDEAL PLASMA

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In recent years studies of shock and detonation wave phenomena at extreme conditions have been conducted at proton radiography facility developed at the ITEP Terawatt Accelerator (TWAC-ITEP). The 800 MeV proton beam intensity in these experiments is about 10^{10} particles per pulse. A single beam bunch consists of four consequent 70 ns long micro bunches with 250 ns intervals between them. The spatial resolution of the facility that was measured in static experiments is about 50 μm. For the generation of shock waves the energy of high explosives (HE) is used, therefore experimental targets are placed within the explosive containment chamber that is certified for the use of up to 100 g of HE in TNT equivalent. The results of latest experiments are presented, including results on explosion and detonation of pressed and emulsion high explosives, shock-induced dense non-ideal plasma of argon and xenon and shock loading of non-uniform metal surfaces.

Measurement of the Compressibility of Deuterium and Helium Plasma at a Pressure of ~ 2000 GPa

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The results of measuring the quasi-isentropic compressibility of helium and deuterium plasma in the pressure range 1500–2000 GPa by means of experimental devices of spherical geometry and X-ray radiographic complex consisting of three betatrons and a multichannel optic-electronic system of the detection of X-ray radiographic images are presented. The densities of compressed deuterium and helium plasma 4.3 g/cm^3 and 3.8 g/cm^3 at the pressures P ~ 2210 and ~1580 GPa respectively have been detected. The internal energy of deuterium plasma at this pressure amounts ~1 MJ/cm^3 that ~100 times exceeds the specific energy of chemical condensed high explosives. The analysis shows that the ionization degree of helium at the reached compression parameters amounts ~0.9.

Measurement of the Quasi-isentropic Compressibility of Helium Plasma at a Pressure of ~5000 GPa

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The results of measuring of quasi-isentropic compressibility of helium plasma by means of an experimental device of spherical geometry and X-ray radiographic complex consisting of three betatrons and a multichannel optic-electronic system of the detection of X-ray radiographic images are presented. The density of compressed helium plasma ~9 g/cm^3 at the pressures around 5000 GPa has been detected. The analysis shows that helium at the reached compression parameters is found in a single ionized state.

Electrical and thermalphysics properties of lithium hydride and manganese oxide at high pressures and temperatures.

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The experimental results of electrical properties of shock compressed litium hydride (LiH) and manganese oxide (MnO) are presented in a range of pressures up to 100-150 GPa and temperatures up to 1500-2000 K. The source experimental information (conductivity profiles) represents the sample conductivity directly during microsecond times of its temperature-volume history at shock compression.

Pressure was created by impact of plane metal projectiles. They have been accelerated by detonation products of explosive till kilometers speeds. Layer measuring cells were used. They consisted of plates-anvils and plates electrical insulating films which contained the investigated sample. It provided its step shock compression. Shock wave electroconductivity experiments of investigated materials were supplemented with the semiempirical description of thermophysics properties of its with the subsequent mathematical modelling and the analysis of results.

It is shown that in the pressure region 95 GPa and temperatures 2500 K lithium hydride samples get conductivity at the level of 0.1 (1/Ohm). It is possible to explain such behaviour of lithium hydride both melting, and polymorphic transition to the high pressure phase. In the assumption of phase transition the equilibrium line of this transition is constructed in the range 50-320 GPa

Manganese oxide conductivity increases in orders of magnitude and reaches values which are characteristic for metals. On the basis of experimental results and calculated temperatures and pressures the trajectory of occurrence of high conductivity is found on the phase diagram of this oxide. The conductivity manganese oxide change is interpreted as Mott insulator-metal transition in the region 30-60 GPa and 2000-4000 K.

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Simulations of nonideal plasmas by the method of molecular dynamics with wave packet splitting

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The method of classical molecular dynamics (MD) is widely used to simulate equilibrium and nonequilibrium nonideal plasmas [1,2]. At the same time the applicability of MD is restricted to non-degenerate and fully ionized plasmas. Such a model is often too rough if applied to real experimental conditions. One of the possibilities to improve the method of MD without loosing its performance benefits is to consider electrons as wave packets [3]. In this case the problem of choosing effective electron-ion interaction potential does not arise, the accuracy of simulation of an individual particle collisions is increased and ionization-recombination processes are represented in a better way. Furthermore the exchange interaction between electrons in the Hartree-Fock limit can be taken into accounts using antisymmetrized wave packets [4]. This method was named Wave Packet Molecular Dynamics (WPMD).

Problems of the existing implementations of this approach are the poor accuracy for a bound state of electron an ion and spreading of wave packet for a weakly bound electron [5]. We propose to address both issues using a new technique based on expansion of the wave function for each electron in the bases of multiple Gaussians. Calculations of the ground state energies of H and He show that this method provides accuracy of less then 1% for even three Gaussians per electron. Another advantage of the new technique is the possibility to study quantum effects related to the wave function splitting such as penetration through a potential barrier. As a test case we consider tunnel ionization of a hydrogen atom in a short laser pulse. It is shown that the results of the new method are in a good agreement with quantum-mechanical calculations.

In future it is planned to apply the new method to model bound states of electrons and ions in nonideal plasmas and combine it with the classical Coulomb interaction model for free electrons.

1. I.V. Morozov, G.E. Norman // Journal of Experimental and Theoretical Physics (JETP), **100,** 370 (2005).
2. T. Raitza, H. Reinholz, G. Röpke, I. Morozov, and E. Suraud, Contrib. Plasma Phys. **49**, 496 (2009).
3. D. Klakow, C. Toepffer, P. G. Reinhard, J. Chem. Phys. **101**, 10766 (1994).
4. B. Jakob, P. G. Reinhard, C. Toepffer, G. Zwicknagel, J. Phys. A **42**, 214055 (2009).
5. I.V. Morozov, I. A. Valuev, J. Phys. A **42**, 214044 (2009).

Simultaneous pressure (with imaging interferometer) and temperature measurements of lead vapor impact on sapphire wall in ion-beam driven experiments

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A results of experiments, performed at HHT area of GSI will be presented. An imaging displacement interferometer in a Twyman-Green configuration has been used to record a motion of a surface of sapphire window due to the impact of expanding target material (lead), heated by short pulse of uranium ion beam; distances between sample and window varied from 0.4 to 1.5 mm. Spatial and temporal velocity profiles allowed to calculate the pressure of a vapour layer near sapphire surface. Pressure distribution along the surface due to quasi-gaussian spatial profile of ion beam was clearly visible. Optical multichannel pyrometer was used to simultaneous recording of a lead surface and vapour temperature. The narrow-band dielectric mirror coating of a rear surface of sapphire window allowed to reflect the interferometer laser wavelength, remaining transparent to pyrometer bands. Pressures up to several kBars and temperatures more than 10 kK were recorded.

The heating of dust particles motion in gas discharge plasma

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In laboratory experiments it has been found that dust particles can acquire a kinetic energy of 10 eV and higher, significantly higher than the ion temperature and electron temperature in a gas-discharge plasma under certain conditions. The average kinetic energy of horizontal motion may significantly differ from the average kinetic energy of vertical motion of dust particles. Admissibility of the concept of "temperature" to describe the motion of dust particles and the equality of the average kinetic energy and "temperature" also raises many questions in the community. In this paper we attempt to formulate a mechanism of energy transfer in plasma-dust system to explain the anomalous heating of the oscillations of dust particles on the basis of the joint influence of various forces and phenomena, also we attempt to justify the validity of using the term "temperature" and find out the boundaries of the applicability of this term.

A system of equations of motion of dust particles in a gas discharge is formulated in view of the charge fluctuations and features of near-electrode layer of the gas discharge. A molecular dynamics simulation of dust particles motion is performed. Using molecular dynamics method allows us to take into account the effect of all the known phenomena, including nonlinear and stochastic, in the aggregate on the motion of dust particles. Varying the parameters of the equations of dust particles motion allows us to avoid the problem of the lack of exact values of some parameters of plasma-dust system. A mechanism of energy transfer from vertical to horizontal motion is based on the phenomenon of parametric resonance. The theoretical calculations agreed with the molecular dynamic simulations. The scheme of energy transfer in plasma-dust system is formulated.

RADIATION PROPERTIES OF PLASMA IN THE PROBLEMS OF HIGH ENERGY DENSITY PHYSICS

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Theoretical and experimental studies of radiative properties of hot dense plasmas have been carried out depending on the plasma composition. Important features of the theoretical model, known as the ion model of plasma, are discussed. This model can be applied for theoretical estimations of radiative efficiency of X-pinch wire materials. Theoretical estimations of radiative efficiency are compared with experimental data that have been obtained from measurements of X-pinch radiation energy yield using two exploding wire materials, NiCr and Alloy 188. The theoretical approach, which was developed and used in previous studies, is applied to temperature diagnostics of low Z foams (C12H16 O8) и (C8 H12 O6) heated to plasma in combined laser — heavy ion beam experiments.

QUARK-GLUON PLASMA IN EXTREMELY INTENSIVE MAGNETIC FIELDS

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The extremely intensive magnetic fields can be generated in the noncentral heavy ion collisions, these fields drastically change the properties of the quark-gluon plasma which is produced in the collisions. The interference of the strong and electromagnetic interactions leads to the new effects which can be observed at experiments. We present the results of the numerical simulations of quark-gluon plasma in the background of extremely intensive magnetic fields.

Formation of dense dust structures and structural phase transitions in cryogenic plasma in neon

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Characteristics of dust structures depend on Debye radius. Cooling of dusty plasma to cryogenic temperature leads to diminishing of distance between particles and leads to increasing of dust structures density. The formation of filamentous disordered clusters was observed in a glow discharge.

In this paper we first experimentally obtained the pressure - current phase diagram of the dust structures of micron size particles in cryogenic dusty plasma in neon at the of liquid nitrogen temperature and pressure of 0,14-1,4 torr. It was found that the distance between dust particles and forms of dust structures have a complicated dependence on temperature of the heavy component, the gas pressure and discharge parameters. The formation of a dense core in the center of the dust structures similar to the "center of crystallization" was observed, when the temperature is lowered to T = 200 K.

Further plasma cooling leaded to the formation of dense uniform structures with distance of 25-40 mm between dust particles, or chain clusters with the distance of 125-150 mm between clusters. The vertical of dust particles were observed, the amplitude of oscillations depended on gas pressure. The observed oscillations of the particles were explained by changes in the longitudinal electric field, which was due to longitudinal temperature and gas density gradient.

In contrast to the observations in air plasma, clusters in neon plasma can form regular structures resembling the nodes of the hexagonal lattice. With increase of discharge current the clusters were observed to melt and the distance between particles and the amplitude of particle longitudinal oscillations increased. The increase of gas pressure leaded to the coagulation of clusters into dense uniform structures.

The increase of discharge current results in diminishing of longitudinal size of dust structure and increase of its diameter. Unlike to experiments at room temperature, in a cryogenic plasma there were not registered the structures with the central area free of particles at the same discharge currents.

Ab initio simulations for warm dense matter: phase transitions and isentropic shock compression experiments

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The behaviour of warm dense matter (pressures of several megabar and temperatures of several eV) is of paramount importance for interior models of giant planets such as Jupiter and Saturn. Strong correlations and quantum effects are important under those conditions which empede accurate predictions for the equation of state (EOS) and the high-pressure phase diagram of even the simplest and most abundant elements H and He. Furthermore, novel phenomena such as proton conduction and demixing are expected to occur in C, N, O, their hydrides, and mixtures at high pressures which are relevant for, e.g., Uranus and Neptune.

We apply ab initio molecular dynamics simulations based on finite-temperature density functional theory to calculate the EOS and the electrical conductivity for H, He, and their mixtures for a wide range of densities and temperatures. For instance, EOS data for hydrogen indicate a first-order liquid-liquid phase transition which is closely connected with a nonmetal-to-metal transition [1,2]. Our results yield a critical point at 1400 K, 1.32 Mbar and 0.79 g/cm^3 [2] – i.e. at much lower temperatures than chemical models have predicted for the plasma phase transition. Based on the ab initio EOS data we compare with available isentropic shock compression experiments [3-5]. The electrical and thermal conductivity, thermoelectric power, and Lorenz number are calculated [6]. We have identified the parameters for demixing of helium from hydrogen [7-9] which match the conditions in the interior of Saturn as long has been predicted.

[1] M.A. Morales et al., Proc. Nat. Acad. Sci. **107**, 12799 (2010).
[2] W. Lorenzen, B. Holst, R. Redmer, Phys. Rev. B **82**, 195107 (2010).
[3] V.E. Fortov et al., Phys. Rev. Lett. 99, 185001 (2007).
[4] M.A. Mochalov et al., JETP Letters **92**, 300 (2010).
[5] G.V. Boriskov et al., Contrib. Plasma Phys. **51**, 339 (2011).
[6] B. Holst, M. French, R. Redmer, Phys. Rev. B **83**, 235120 (2011).
[7] W. Lorenzen, B. Holst, R. Redmer, Phys. Rev. Lett. **102**, 115701 (2009).
[8] M.A. Morales et al., Proc. Nat. Acad. Sci. **106**, 1324 (2009).
[9] W. Lorenzen, B. Holst, R. Redmer, submitted.

High-current discharge channel contraction in high density gas

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Research results for discharges at current amplitudes of 0.5 – 1.6 MA and current rise rate of ~10^{10} A/s are presented. The discharge is performed in the hydrogen environment at the initial pressure of 5 –35 MPa. Initiation is implemented by a wire explosion. The time length of the first half–period of the discharge current is 70–150 μsec. Under such conditions, discharge channel contraction is observed; the contraction is followed by soft X-ray radiation. The phenomena are discussed, which are determined by high density of the gas surrounding the discharge channel. These phenomena are: increase of the current critical value, under which the channel contraction begins; and growth of temperature in the axis region of the channel under increasing the initial density of the gas.

Hydrides of metals at high pressures of shock compression

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In this work results of an experimental research of electrophysical and thermodynamic properties of metal hydrides and hydrogenous substances in areas of phase diagrams which are reached by quasiisentropic compression in a range of pressure 10-150 GPa are presented.

It is known that pressure of transition of pure hydrogen in a metal condition by theoretical estimations makes more 400 GPa at room temperature. However, these parameters are difficultly achievable in practice, as in diamond anvils where it is physically impossible to create such pressure, and in the conditions of dynamic compression because of a strong warming up of the sample at such pressure. At the same time there is a class of hydrides of metals and hydrogenous substances which in usual conditions being dielectrics, at pressure 90-150 GPa possess metal conductivity, and conductivity is caused by atoms of hydrogen, instead of presence of atoms of metals in a molecule.

Depending on the communication nature all hydrides conditionally share on covalent, ionic and like-metal hydrides. Interest to studying of covalent hydrides is caused also by that fact that conductivity occurrence in them is connected basically with effect of so-called chemical precompression of hydrogen in a molecule.

In this work electrophysical and thermodynamic properties covalent, ionic and like-metal hydrides on example LiH, MgH2 and TiH2 accordingly are investigated. It is shown that in the conditions of step compression up to 140 GPa these hydrides get conductivity at level 0,1-2 Ohm^{-1} which correlates with polymorphic transitions between high pressure phases.

The Presidium RAS Program of Basic Research «Thermal Physics and Mechanics of Extreme Energy Effects and Physics of Strongly Compressed Matter» supported this study

Plasma flow in a laser target as used in the CRASH project and its sensitivity to the Equation-Of-State for non-ideal plasmas and a Warm-Dense Matter

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A xenon plasma flow in a laser target as used in the Center for RAdiative Shock Hydrodynamics (CRASH) incorporates the strong shock wave (see [1]). A high-energy-density in xenon at the pressure about 1 Barr, is generated using a ten-beams channel of the Omega laser, the total energy of the laser shot being ~4 kJ. Under these circumstances the shocked xenon intensely radiates the X-ray emission.

It is known from numerous studies of the strong explosions in the atmosphere that the strongly radiating shock wave while sliding along the solid surface (in the discussed application this is the ground surface) may suffer a significant reconstruction of its shape, which phenomenon is called the Taganov effect. On having been emitted from the shock-heated gas behind the shock wave front, the radiation heats up the perfectly opaque solid surface. As the result, the temperature of the air layer adjacent to the ground surface grows up due to heat conduction. The shock wave may propagate along this layer at the speed greater than that for the shock wave propagation along the unperturbed xenon, resulting in an essentially non-planar shape of the shock front, with a runaway precursor.

In the laser targets as used in the CRASH project the flow configuration may occur which is physically similar to that accompanying the Taganov effect. The X-ray radiation emitted from the shocked xenon is then absorbed in the plastic wall of a cylindrical gas-filled capilary, along which the shock wave propagates. The radiation fluxes are so intense, that well prior to the shock wave arrival the wall material is heated upeV temparatures. The ablation of the wall material occurs to converge towards the axis of symmetry, forming as the result the convergent conical shock wave in xenon. Similarly to what happens in the course of the Taganov effect, the interaction of this convergent wave with the original shock wave as propagating along the capillary may modify the shock wave geometry

The easily observable in the experiment as well as in the numerical simulations, the modification of the shock wave configuration appears to be sensitive to the choice of the equation of state for the wall material. In the present work we compare the variants of the numerical simulation of the flow in the CRASH target with the use of different equations of state for the wall material (polyimide) The choice of the EOS which is in the best agreement with the experiment may allow to choose the better model for a plastic under the conditions when the material is not only a non-ideal plasma, but it is also a “warm dense matter” (WDM) The numerical models for the equation of state and opacities are provided by several groups from Russia, USA, France and Switzerland. Numerical simulations are preformed within the approximation of radiation hydrodynamics with multi-group diffusive radiation transport.

[1] R.P.Drake et al, High Energy Density Physics, 7(1), 130-140 (2011)

Atomistic simulation of laser ablation of metals

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Laser ablation has many technological applications in material microprocessing and fabrication of nanostructures. There are still a lot of gaps in the understanding of the mechanisms of laser ablation of metals, especially for ultra-short pulses. The penetration of pulsed laser radiation into a substance at ablation is accompanied by strong heating of the electron subsystem. The time of electron-ion relaxation is comparable to the time of ablation itself and to the times of accompanying processes (heat transfer, phase transitions etc.) Thus, the laser ablation process occurs in extremely nonequilibrium state of two-temperature warm dense matter state. Warm dense matter is the state between the heated condensed matter and plasma. Now the correct theoretical description of such a state is not developed.

In this work, the investigation of laser ablation is performed for gold and aluminum films. We use the developed atomistic two-temperature model. This model describes lattice subsystem by means of classical molecular dynamics while the electron subsystem is considered in the continuum approach. In such way, the Newton's equations for ions dynamics and the heat conduction equation for evolution of electrons are solved in model. The energy transfer from the electron to ion subsystem is simulated by introducing a thermostat into the molecular dynamics model. In addition, the interionic potential is depended on local electronic temperature.

The dependences of crater depth on the absorbed fluence at various characteristics of laser pulse are calculated. The various mechanisms of ablation are analyzed. The key role of electronic pressure is marked at description of this process. The comparison to the experimental data is performed.

On the thermal force acting on dust grain in fully ionized plasma

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The dynamics of dust particles plays an important role in different plasma environments [1,2]. One of the most common, acting on a dust grain, is the drag force, occurring due to the momentum exchange between plasma particles and the dust grain. One of the components of this force is the thermal force, arising from the temperature gradients of plasma species.

In laboratory dusty plasma experiments [1,2], where the plasma temperature and degree of ionization are small, the thermal force due to neutral particles is usually considered. However, recently the dynamics of dust particles in fusion devices brought significant attention from researchers. In order to describe the dynamics of the dust particle it is necessary to account for various forces, including the thermal force. The degree of ionization in hot fusion plasma is high, the plasma temperature exhibits large gradients, therefore the contribution from charged particles to thermal force becomes dominant.

The expressions for the thermal force, acting on an ion, are well known [3]. However, unlike the ions, a dust particle has finite size and therefore experiences not only Coulomb collisions with plasma ions and electrons but also the collisions, leading to the absorption of charged particles. The general expression for the calculation of the thermal force is:

$$\vec{F}_{dj} = m_j \int d^3\vec{v}\, \sigma_{dj}(v)\, v\vec{v} f_j(\vec{v})$$

where m_j, $f_j(\vec{v})$ is the mass and the distribution function of the particle specie "j", $\vec{v}$ is the relative velocity of the particle and the dust grain, $\sigma_{dj}(v)$ is the dust-particle collision cross-section.

The general expressions for the ion and electron thermal forces and the electron friction force, acting on a spherical dust grain in the magnetized fully ionized plasma, were obtained in this paper. The distribution function $f_j(\vec{v})$ was taken in the 21-moments approximation of Grad's method. In addition, it was considered, that the dust grain has negative or weak positive charge and its radius is much smaller than gyroradii of ions and electrons [3]. The contributions of scattering and absorption collisions to these forces were considered. It was obtained, that depending on the grain size either of these components can dominate. For the case where the Debye length is smaller than the radius of the dust grain, the absorption related component of thermal force dominates. In the opposite case the component due to the Coulomb scattering of plasma particles prevails. Moreover, it was shown, that the forces found in the paper can play the significant role in the dynamics of dust grain in fusion devices with the stagnated plasma flow.

This report was prepared on basis of materials of the eponymously-named paper "On the thermal force acting on dust grain in fully ionized plasma" [4].

References.

1. P. K. Shukla and A. A. Mamun, Introduction to Dusty Plasma Physics (Institute of Physics, Bristol, 2002).
2. Complex and Dusty Plasmas, edited by V. E. Fortov and G. E. Morfill, (CRC Press, Taylor & Francis Group, Boca Raton, London, New York, 2010).
3. S. A. Khrapak, A. V. Ivlev, S. K. Zhdanov, and G. E. Morfill, Phys. Plasmas 12, 042308 (2005).
4. A.A. Stepanenko, R.D. Smirnov, V.M. Zhdanov, S.I. Krasheninnikov, Phys. Plasmas 18, 033702 (2011).

Role of the quasi-bound and continuum states in the thermodynamic properties of non-ideal molecular gases at elevated temperature. Classical and quantum approach.

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The new frontiers of space exploration require the solution of many problems concerning hypersonic aerodynamics to obtain the best spacecraft configuration for reentry. In particular, during the entrance of supersonic aircraft into the upper atmosphere of solar system planets high-speed gas-plasma medium is formed. To elucidate the fundamental energy exchange processes between the internal degrees of freedom of atoms and molecules in such highly heated medium thermodynamic and transport properties of real gases at the temperature *T* up to 50 000K are necessary. To this end, the statistical calculations should apparently account for both interatomic and intramolecular (nonadiabatic) interactions taking place between the constituent particles.

We present results of comparative analysis of the quantum, classical and quasi-classical methods of calculations on thermodynamic properties of hydrogen and nitrogen dimmers in a wide range of the temperature. In particular, the internal partition function and the specific heat of the relevant species have been evaluated and compared with existing results. In general, at low temperature, a good agreement is observed, whereas the pronounced deviations occur at elevated temperatures when quasi-bound, continuum and electronic states start contributing. The full form of the interacting-particle partition function is found to be essential to complete and correct calculation of the thermodynamic functions of the system. Obviously, conventional methods which include only the bound-state sum in partition function become in error since it introduces discontinuities into the thermodynamic-state function at those points where the bound-state levels pass into the continuum. In the case of low temperatures ($\omega_e \gg kT$) the calculation should be carried out by the quantum method and non-adiabatic interaction should be apparently taken into account. At high temperatures ($\omega_e \ll kT$) the calculation could be carried out with appropriate accuracy in the framework of classical statistical mechanics while at intermediate temperatures ($\omega_e \sim kT$) a quasi-classical correction is necessary to use.

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EXPERIMENTAL INVESTIGATION OF THE ACTION OF A MAGNETIC FIELD ON DUST PLASMA STRUCTURES IN A GLOW DISCHARGE DEPENDING ON THE DISCHARGE PARAMETERS

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We have investigated the influence of a longitudinal static magnetic field on the dynamics of dust structures in strata of a dc glow discharge. Our aim is to study the influence of various parameters of the discharge on the rotation of dust structures in stratified discharges under the influence of a magnetic field to better understand the mechanisms of such effects.

The experiments were performed with the setup described in [1]. Glow discharge was ignited in a cylindrical glass tube of diameter 4.6 cm filled with argon. Shape of the electrodes is conical, the distance between them is 55 cm. Magnetic field created by two coils, covering the discharge tube and positioned so that the stratum of dust particles was in the uniform field between the coils. Polydisperse particles Al_2O_3 injected into the plasma by means of a container at the top of the tube. Visualization of dust particles was carried out using laser beam, which was formed by a cylindrical lens into a laser "knife" of a thickness about 200 μm in horizontal or vertical planes. We observed rotation of the dust structure when passing current through the coils. The motion of particles was fixed by speed camera (250 frames/s). The dependences of the rotational velocity on the discharge current and gas pressure have been obtained. Experimental results are analyzed and compared with data from other papers [2,3]. Estimates and preliminary calculations show that our experimental data are in agreement with the theoretical concepts about mechanisms of dust structure rotation in a magnetic field, developed in [4].

Литература:

[1]. Ramazanov T.S., Dosbolayev M.K., Dzhumagulova K.N., Jumabekov A.N., Phys. Plasmas, 2008. **15**. 053704.
[2]. Karasev V.Yu., Dzlieva E.S., Ivanov A.Yu., Eikhval'd A.I., Phys. Rev. E, **74** (2006) 066403.
[3]. Vasiliev M.M., D'yachkov L.G., Antipov S.N., Petrov O.F., Fortov V.E., JETP Lett. **86** (2007) 358.
[4]. Vasiliev M.M., D'yachkov L.G., Antipov S.N., Huijink R., Petrov O.F., Fortov V.E., EPL **98** (2011) 15001.

Temperature measurements and hydrogen transformation under dynamic compression up to 150 GPa.

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Final temperature of dynamically compressed hydrogen was investigated for the pressures 100-150 GPa with temperatures being 2500-5500 K. Anomalous temperature pike at the end of compression stage was registered in all the experiments. Registered low temperature profiles shapes differ from that obtained in hydrodynamic simulation. These effects were described by formation of metal hydrogen film on the cold surface of LiF. In high temperature experiments metal film was dissolved. Optical emission of hydrogen with T=6800 K and P=150 GPa was not registered. It appeared to be optically transparent.

Experimentally obtained points in p-T diagram for dielectric and metal states of hydrogen are in a good agreement with the model [1] predictions.

Literature.

1. Pyalling, A. A., "Semiempirical Multiphase Equation of State for Hydrogen. High Temperature", Vol. 48, pp. 163–169, 2010

FORMATION OF THE CORONA AND DENSE CORE IN THE DISCHARGE CHANNEL IN THE ELECTRIC EXPLOSION OF WIRES

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In the numerical calculations it was obtained that, during the explosion of a single aluminum wire, the core material remains for a long time in the state of a dense nonideal plasma with a temperature of 1–3 eV. Only after shunting the main part of current to the corona, the core goes into a two-phase liquid-vapor state in the expansion process. However, if shunting of the current occurs at an early stage of the explosion, for example, when the wire material is still in liquid state, it is possible another scenario of core structure formation. In this case, due to a sharp drop of the compressive magnetic pressure, the core material can come into a state of the stretched melt during unloading. In accordance with the molecular dynamic calculations this metastable state decays, that resulting in to formation of a complex core structure: the outer cylindrical liquid shell filled with low-density foam. The foam decays into liquid droplets before the outer shell breaks apart. Simulated density profiles demonstrate good qualitative agreement with experimental high-resolution X-ray images showing the complex hollow structures within the long-living dense core.

The Russian-European space experiment "Plasma Crystal – 4 Columbus" – objectives and status of works.

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The project "Plasma Crystal - 4" is logic continuation of the previous projects "PK-1", "PK-2", "PK-3" and "PK-3 Plus" on investigation of dusty-plasma structures onboard manned orbiting stations under microgravity conditions. Its main distinctive feature is the original design of the discharge chamber of the tubular extended form doing possible experiments on studying of flows of highly nonideal dusty-plasma liquids and propagation of different types of dusty plasma waves.Besides, the apparatus is equipped by a number of various dusty plasma manipulators (a powerful laser beam, mobile RF-inductor, a ring electrode and a local heater), allowing considerably to expand a spectrum of performing experiments. Experiment "PC 4", initially beginning as Russian-German (directors, JIHT the Russian Academy of Sciences and Institute of Extraterrestrial Physics, Germany), has expanded the geography and includes now participants from many countries of Europe, the USA and Japan.

The present report will include following sections on the project aims, its history, and status of works of the "Plasma Crystal – 4 Columbus" ("PC 4C") experiment:

- the scheme of the space experiment "PC 4C" and a functional purpose of various parts of space equipment;
- the scientific program of planned experiments onboard the ISS;
- the basic results of testing of equipment "PC 4" onboard specialized plane A-300 Zero-G;
- last successes in creation KA "PC 4C" and the scheme of its arrangement in the European module "Columbus" onboard the ISS.

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1. V. Fortov, G. Morfill *et al.*, Plasma Phys. Control. Fusion **47**, 537B (2005).
2. A.D. Usachev, A.V. Zobnin, O. F. Petrov, V.E. Fortov *et al.*, PRL **102**, 045001 (2009).

On dynamics of dust particles near an electric probe in glow discharge plasma.

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Dynamics of dust particles in the positive column of glow discharge was experimentally studied and trajectories of dust particles around the electric probe with taking account of the ion drag and neutrals friction forces numerically calculated. [1,2]. By mean of the introduction of dust particles in the plasma the presence of a positive ion layer around the probe which is negative relatively to plasma,was visually detected . The size of ion layer was evaluated. Trajectories of dust particles, which depende on pressure in the discharge tube were investigated. The results showed that with increase in pressure trajectory of dust particles considerably varies. Large-angle deflection of the particles from the initial trajectory and rotation of a dust particle around the probe was observed. Numerical calculations show that with increase in pressure the ion drag force influences stronger than the neutrals friction force and increases the attraction of dust particles to the probe.

[1] T.S.Ramazanov, et al., *J.Phys.A:Math.Theor.,***42,**214026(2009).

[2] T.S.Ramazanov, et al., *Physics of Plasmas* **15,** 053704(2008).

Experimental investigation of dynamics of dust particles in a corona discharge

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The possibility to use a corona discharge to form dusty structures in different dusty-plasma mediums has been investigated. At the present time techniques to confine dust particles in dusty-plasma structures at pressures below 10 Torr in the glow, high frequency and nuclear-induced plasma are known. But for a number of applications there is a necessity to form dusty-plasma structures at higher pressures. In this case the corona discharge providing more uniform ionization of a gas in a comparison with a streamer discharge seems to be a promising one. The investigation was performed at atmospheric pressure in air, neon and argon. The corona discharge was initiated in a volume restricted by a quartz cylindrical tube and in a freely burning discharge. The tubes with internal diameters of 20 and 50 mm were used. The distance between electrodes was equal to 28 mm. we used conducting (brass) and dielectric particles with sizes from 50 μm up to 2 mm. It has been revealed that particles distributed at a surface of a low electrode were escaped from the electrode surface and moved to the upper electrode or leave the interelectrode volume only after the corona discharge ignition.

The conditions of formation of mono- and multilayer dusty structures in plasma of rf-discharge

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Formation of structural phase transitions is of great interest on both practical and theoretical grounds and at present time, it is a subject of intensive theoretical and experimental studies in various areas of physics. Growth of interest to problems related with behavior of dusty plasma particles is connected with development of a wide range of applications, including possibility of a retention and control of attitude position of nanoscale objects [1].

At present work we present the experimental study of conditions of formation of monolayer and multilayer systems of dust particles in plasma of rf-discharge. Experiments have been carried out for argon (pressure from 0.1 to 0.3 Torr) with melamine formaldehyde particles of radius 6,37 microns with discharge power from ~ 2 to 30 W. Velocities and displacements of dust particles, their kinetic energies, concentrations, pair correlation functions and dynamic characteristics are measured. Experimental analysis of redistribution of kinetic dust energy on degrees of freedom in monolayer and multilayer systems is carried out. New data related to the formation of configurational phase transitions in two-dimensional dusty plasma systems is obtained. Comparison with the existing numerical and theoretical data is considered.

It should be noticed that during experiments a formation of new dust layer have been observed with decrease of the discharge power at constant pressure as well as with decrease of pressure of buffer gas at constant discharge power. (In both cases an increase of concentration of dust particles has been observed; in addition a decrease of gas pressure leads to reducing of a gradient of vertical electric field in near-electrode area of rf-discharge). In contrast to experimental observations presented in work [2], with decrease of discharge power, the spatial correlation of particles has been destroyed and their kinetic temperature has been increased in a layer plane.

References.

[1] Ostrikov K, Cvelbar U and Murphy A B 2011 *J. Phys.* D **44** 174001

[2] Melzer A, Homann A and Piel A 1996 *Phys. Rev.* E **53** 2757

Theoretical models of stellar atmospheres of giant stars as an important element for pixel-lensing and exoplanet searches

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Pixel-lensing searches are very important for dark matter distributions in our and Andromeda galaxies. As it was shown pixel-lensing is a very efficient tool for exoplanet searches (including exoplanets near the habitable zone). Moreover, the anomaly PA-99-N2 can be explained with an exoplanet mass about 5—7 Jupiter mass. Since giant stars are very important for pixel lensing, since only their lensing can lead to observational signatures, a creation of detailed models of giant stars and models for atmospheres of giant stars, in particular, are very important. A creation of models for giant star atmospheres are based on approaches of the ATLAS type developed by Kurucz (1970) and their modifications. An improvement of these models based on new atomic databases and new computer facilities is very important for a development of advanced models of pixel-lensing.

Quark-gluon plasma as quantum liquid

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Аннотация

We review briefly the arguments in favor of considering the quark-gluon plasma observed at RHIC as quantum liquid. We argue, furthermore, that the two-component liquid model describes naturally the basic features of the plasma. The dynamis of the quark-hadron phase transition is discussed within framework of holographic models of Yang-Mills theories.

THE INVESTIGATION OF S - AND P-POLARIZED REFLECTIVITY PROPERTIES OF SHOCK-WAVE COMPRESSED DENSE XE PLASMAS

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For further development of nonideal plasma physics, investigations of it's electronic subsystem properties appear to be crucial. The analysis of the response of dense plasma to electromagnetic waves of moderate intensity can be used as a tool to investigate the validity of the physical models describing the behavior of matter under extreme conditions, high temperatures and pressures. The integration of corresponding Maxwell equations with angular dependence experimental data of s - and p-polarized reflectivities at several wavelengths can be used to construct the spatial profile of the density of charge carriers.

The results of new experiments on reflectivity of polarized light on nonideal xenon plasma are presented. The study of polarized reflectivity properties of plasma was accomplished using laser light of wavelength $\lambda = 1064$ nm and $\lambda = 694$ nm.

In order to measure the dense xenon plasma polarized reflectivity coefficient, the pulsed YAG, Ruby laser system with electro-optical shutter and four-channel pulse high-speed device has been used. The device allows to measure the intensity of the reflected laser beam for four azimuthal angles and was equipped with filters for selection of frequency of probing. The measurements of polarized reflectivity coefficients of explosively driven dense plasmas have been carried out at incident angles up to $\theta = 65$ degrees simultaneously for s- and p-polarization, respectively.

For determination of the equilibrium properties of explosively driven plasma, appropriate gas dynamics calculations were carried out. The plasma composition was calculated within a chemical picture [1]. During the experiments, the plasma density up to $\rho = 2.8$ g cm^{-3}, pressure up to P = 12 GPa and temperature up to T = 32000K were realized. Under these conditions, the plasma is non-degenerate.

The integration of Maxwell equations are based on an interpolation formula for dc conductivity.

[1] Ebeling W, Förster A, Fortov V, Gryaznov V K and Polishchuk A 1991 *Thermophysical Properties of Hot Dense Plasmas* (Stuttgart: Teubner)

STUDY OF TITANIUM AND CERIUM PROPERTIES UNDER SHOCK-WAVE LOADING

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The report presents results of experimental study of cerium and titanium behavior under shock-wave loading, results on measurement of sound velocities in shock-compressed materials. The experiments were performed with two systems for loading of investigated samples. The loading systems are based on a light-gas gun and explosive generators of shock waves. PVDF gauges and manganin gauges of dynamic pressure were used for measurement of pressure profiles. The samples were manufactured using electrolytic cerium of the type TsE-0 (ST48-295-85) having purity of 99.83% and technically pure titanium VT1-0 (the titanium content is 99.3 weight %). Post-test investigation of material was performed by the methods of optic metallography and X-ray structural analysis. Results of research of the cerium samples, which were recovered after loading, revealed by the method of optical metallography that damage consisted of spall cracks. For each cerium sample, we determined depth of spall layer, width and structure of the damage zone. X-ray structural analysis revealed no changes in the cerium phase structure. CeII (γ-Ce) is the basic phase in all samples before and after shock loading. It has a face-centered cubic structure. All the recovered titanium samples consist of two phases: α-Ti and ω-Ti.

Sound velocities were measured in titanium by the rarefaction oncoming technique with use of piezoresistive gauges basing on manganin and rarefaction overtake technique with use of the indicator liquids. It was obtained that the strong kink of dependences of sound velocities was observed when pressures were 50 - 90 GPa on the shock adiabat of titanium. It can be caused by phase transition of titanium, including melting.

Ab-initio calculations of the thermal conductivity of metals with hot electrons

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JIHT RAS

The interaction of ultra-short laser with metal result in the two-temperature (2T) state in which the temperature of the electronic subsystem (Te) by orders of magnitude greater than the ion temperature. Description of 2T state is important for understanding the mechanisms of laser ablation, since at this stage number of relevant phenomenon occurs: transfer of laser energy to the ions, creation of warm layer which determine the future dynamics of the system. The numerical simulation of laser ablation requires the kinetic coefficients of the metal with hot electrons. However, phenomenological dependencies are mostly used with contains adjustable parameters determined from the asymptotic behavior at low and high Te. Ab-initio methods don't have such deficiencies, because there are no adjustable cofficient. This paper presents a ab-initio calculation of the thermal conductivity of the metal with hot electrons, calculated from the Kubo-Greenwood formula. The calculation is performed for liquid aluminum in the range of Te from 0 to 6 eV. The dependence of thermal conductivity is in a good agreement with calculations from kinetic equation [1].

References:

[1] Inogamov N.A., Petrov V.Y. / / Thermal conductivity of metals with hot electrons / / JETP, 2010, T. 134, ¹ 3, pp. 505-529

Numerical simulation of a dusty cloud in the Neon glow discharge stratum

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ОИВТ РАН

Results of the self-consistent simulation of a dusty plasma structure formation are presented. The dusty structure is formed by mono-disperse grains in the standing stratum of the neon direct current discharge in the non uniform discharge tube. The simulation results are compared with experimental observation of the dusty cloud formation under appropriate conditions. The plasma parameters in the stratified part of the discharge, investigated by optical methods are presented also.