15th International Conference on the Physics of Non-Ideal Plasmas Almaty, August 30- September 4, 2015

PNP

Book of Abstracts

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Preface

Dear, Colleagues!

We welcome you to the 15th International Conference on the Physics of Non-Ideal Plasmas (PNP15) in Almaty. The conference venue is the Best Western Plus Atakent Park Hotel located in the center of the "Apples' City" - Almaty and a part of the largest exhibition center in Kazakhstan and Central Asia – Atakent.

The conference continues an already traditional series of meetings that specifically focus on theoretical and experimental investigations in the field of non-ideal plasma physics. Started as a small topical workshop in Matzlow-Garwitz, Germany in 1980 and continued in the subsequent meetings in Wustrow (1982), Biesenthal (1984), Greifswald (1986), Wustrow (1988), Gosen (1991), Markgrafenheide (1993), Binz (1995), Rostock (1998) and Greifswald (2000), an international character of the event resulted in that the PNP-12 was first held outside Germany and hosted by the Universidad Politécnica de Valencia, Valencia, Spain in 2003. At present the PNP conference is a triennial event previously held in Darmstadt (Germany, 2006), Chernogolovka (Russia, 2009) and again Rostock (Germany, 2012).

This year Conference is held in Almaty, the former capital of Kazakhstan, located at the foot of the beautiful mountains of Zailiiskii Alatau. The city is a scientific and cultural center of the country and provides a whole variety of opportunities for leisure, entertainment and amusement. Near the city there are the prominent Medeo skating rink, Chimbulak ski resort and Kok Tobe mountain park, which offers the best view over the city.

The Conference is organized by the Al-Farabi Kazakh National University and is supported by the Institute of Experimental and Theoretical Physics and the National Laboratory of Nanotechnology and other sponsors. The scientific program will feature invited and topical talks as well as poster presentations on cutting-edge advances in the field of interest and will cover the following topics:

- statistical physics and *ab-initio* simulations
- production of non-ideal plasmas (using optical lasers, free electron lasers, heavy-ion beams, Z machine, high explosives etc.)
- diagnostics of non-ideal plasmas (using x-ray scattering, line shapes, stopping power, emission and absorption, etc.)
- equilibrium properties, equations of state and phase transitions
- kinetics, transport and optical properties
- dense astrophysical and ICF plasmas
- ultra-intense laser-matter interaction
- dusty plasmas.

We would like to thank scientists from 12 Countries who are attending the PNP15 meeting in Almaty. We have received 109 papers, and the International Program Committee has assembled a very interesting program consisting of 9 invited talks, 50 Topical talks, and 50 posters. This demonstrates the international character of our research and the great interest in the field of non-ideal plasmas.

Almaty is the Kazakhstan's largest metropolis, scientific and educational, cultural and historical, economic and financial, banking and industrial center of the country. The name of the city, Almaty, is translated as “the city of apples”.

Almaty is situated in the center of the Eurasian continent, in the south-east of the Republic of Kazakhstan, at the foothills of the Trans-Ili Alatau Mountains, the northernmost ridge of the Tien Shan. The urban territory of Almaty has more than eight thousand hectares occupied by gardens and parks, squares and boulevards. The total area of the city is 340 km2. The city's population is about 2 million inhabitants. There are representatives of many religions and different nationalities.

Nowadays in Almaty there are 18 theaters, 45 museums and art galleries. It hosts many festivals of different areas of music: jazz, rock festivals, retro festivals. The special status of the city provides that in Almaty head offices of the largest banks in Kazakhstan and subsidiaries of multinational financial institutions and companies are located. There are the National Academy of Sciences of Kazakhstan, Central Asian Geographic Society, Observatory “Kamenskoe plateau”, as well as many leading universities and research institutions.

Many sports complexes such as the Medeo skating rink and Chimbulak ski center, alpinist and tourist camps, health resorts, resort hotels, and campings were constructed on the outskirts of the city. Almaty obtains the international recognition thanks to such prestigious events as “Asian Games 2011”, World Boxing Championships, stages of World Cup in judo and ski jumping, a stage of world “Grand Prix-2013” in volleyball and professional cycling race “Tour of Almaty”. Almaty will host the World Winter Universiada of 2017.

Prof. Dr. Tlekkabul Ramazanov
Chairman of the Local Organizing Committee

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15th International Conference on the Physics of Non-Ideal Plasmas

Conference program

Monday, Aug.31		
8:30	Opening remarks	
9:00	I1 Bonitz	Path integral Monte Carlo for correlated fermions - can we avoid the sign problem?
9:40	T1 Redmer	Ab-initio calculation of the ion feature in X-ray Thomson scattering
10:00	T2 Silvestri	The dynamical structure function of strongly coupled binary Coulomb mixtures
10:20	T3 V. Filinov	Quantum simulations of thermodynamic and transport properties of the quark–gluon plasma
10:40	Coffee Break	
11:10	T4 Maiorov	Complex Plasmas With Ion Flow: Interaction Of Microparticles
11:30	T5 Inerbaev	Non-Equilibrium Charge Dynamics in Strongly Coupled Coulomb Heterogeneous Systems
11:50	T6 Somsikov	What is it dynamical entropy?
12:10	T7 Moldabekov	Ion Potential in Stationary Nonequilibrium Warm Dense Matter
12:30	Lunch & Discussions	
14:00	I2 Fortov	Correlation and Quantum Effects in Non-ideal Plasmas
14:40	T8 Mintsev	Non-Ideal Plasma and Early Experiments at FAIR
15:00	T9 Telekh	On Kr laser-electric breakdown and discharge plasma dynamics
15:20	T10 Dornheim	Permutation blocking path integral Monte Carlo simulations of strongly degenerate non-ideal fermions
15:40	Coffee Break	
16:10	T11 Karasev	The Dynamics of Dust Structures under Magnetic Field in Stratified Glow Discharge
16:30	T12 Fedoseev	Voids in dusty plasma of a stratified DC glow discharge
16:50	Ebeling, Fortov, Deutsch	Special session: In remembrance of academician **Fazylkhan Baimbetov**

Tuesday, Sep.1		
9:00	I3 R. Magyar	Time-dependent Density Functional Theory to Compute Response Properties of Warm Dense Matter and Non-Ideal Plasmas
9:40	T13 Sengebusch	WDM-Diagnostics Using K-Line Emission Profiles of Ar
10:00	T14 Dubovtsev	Dynamic structure factor of Yukawa one-component plasmas
10:20	T15 Khrapak	Internal Energy of the Classical Two- and Three-Dimensional One-Component-Plasma
10:40	Coffee Break	
11:10	T16 Filatova	The Dynamics of Dust Particles in the Plasma Afterglow
11:30	T17 Rosmej	Thermoelectric transport coefficients for warm dense matter including electron-electron collisions
11:50	T18 Cebulla	High pressure phase diagram of MgO and FeO
12:10	T19 Ussenov	The method of plasma diagnostics by measuring the dust-free region near the electric probe
12:30	Lunch & Discussions	
14:00	I4 Iosilevskiy	Non-Congruent Phase Transitions in Non-Ideal Coulomb Systems
14:40	T20 Schöttler	Free energy model for the high pressure solid phases of carbon
15:00	T21 Groth	Configuration Path Integral Monte Carlo Simulation of Non-Ideal Fermions
15:20	T22 Kunakov	Theory of electrostatic probe in dusty plasma, generated by a volume source of fission fragments
15:40	Coffee Break	
16:10	T23 Gryaznov	Thermodynamics of dynamically compressed gases at megabar pressure range
16:30	T24 Ismagambetova	Structural and thermodynamic properties of a nonideal two-temperature dense plasma
16:50	T25 Martynova	Features of Phase Transitions in the Models of Complex Plasma
17:10	**Poster Session I (The Best Western Plus Atakent Park Hotel)**	

Wednesday, Sep.2		
9:00	I5 Tkachenko	Application of the method of moments in plasma physics: new developments
9:40	T26 Reinholz	Equation of State and transport properties in warm dense matter
10:00	T27 Kang	Nuclear Quantum Effect on the Structure, Transport Properties, and Melting of Dense Matter
10:20	T28 A. Filinov	Dynamic properties of dipolar bosonic bilayers: The sum-rule approach vs. stochastic reconstruction
10:40	Coffee Break	
11:10	T29 Bystryi	Oscillations and electron emission from laser produced cluster nanoplasma
11:30	T30 Ott	Transport in Strongly Correlated Plasmas: Influence of Magnetic Fields
11:50	T31 Apfelbaum	The calculations of thermophysical properties of Fe plasma
12:10	T32 Hou	Equations of state and transport properties of mixtures in the warm dense regime
12:30	Lunch & Discussions	
14:00	**Excursion to Medeu and Shymbulak**	

Thursday, Sep.3		
9:00	I6 Nettelmann	Mixtures of warm dense H, He, and ices,with application to giant planets
9:40	T33 Hoffmann	High Energy Density Physics at GSI and Preparations for the experimental Programme at FAIR in Darmstadt
10:00	T34 E. Son	Strongly Coupled Plasma under External Sources of Ionization
10:20	T35 Zhao	High Energy Density Physics and Ion-Beam Plasma Interaction Based on Large Scale Heavy Ion Accelerators in China
10:40	Coffee Break	
11:10	T36 Dyachkov	Simple Analytical Model of Classical Coulomb Cluster in a Cylindrically Symmetric Harmonic Trap
11:30	T37 Sukhinin	Dust solitons in reactive plasma of a spherical glow discharge
11:50	T38 Kaehlert	Influence of ion magnetization on the dust wake potential and the ion-dust streaming instability
12:10	T39 Pal	A Dusty Plasma in a Non-Self-Sustained Gas Discharge at Atmospheric Pressure
12:30	Lunch & Discussions	
14:00	I7 Petrov	Quasi-2D Phase Transitions in Small and Large Plasma-Dust Systems
14:40	T40 Hartmann	Waves in a quasi-2D strongly coupled superparamagnetic dusty plasma
15:00	T41 Filippov	The Electrostatic Interaction of Two Point Charges in Equilibrium Plasmas within the Debye Approximation
15:20	T42 Koss	Melting of Small Clusters in Dusty Plasma
15:40	Coffee Break	
16:10	T43 Vasilyak	Coulomb Structure with a Large Number of Particles in the Dynamic Trap at Atmospheric Pressure
16:30	T44 Valuev	Simulation of Confined System of Charged Particles by Wave Packet Molecular Dynamics
16:50	T45 Dzhumagulova	Computer simulation of the cage correlation functions of Yukawa liquids
17:10	**Poster Session II (The Best Western Plus Atakent Park Hotel)**	
19:30	**Conference dinner (The Best Western Plus Atakent Park Hotel)**	

Friday, Sep.4		
9:00	I8 Hegelich	Non-ideal plasmas in Extreme, Relativistic Fields
9:40	T46 Deutsch	Negative pion stopping and mesomolecules formation in ultradense plasmas of ICF/WDM concern
10:00	T47 Fokin	Continmual-Atomistic Simulation of the Behaviour of Substance Under the Action of Double Femtosecond Laser Pulses
10:20	T48 Ludwig	Dynamical screening and wake effects in classical, quantum, and ultrarelativistic plasmas
10:40	Coffee Break	
11:10	I9 Davletov	Charging of polarizable dust particles in the orbital motion limited approximation
11:50	T49 Popel	Dust and Dusty Plasmas at the Moon: Recent Research and Future Lunar Missions
12:10	T50 Vasiliev	Formation of Coulomb structures in a magnetic trap under cryogenic temperatures
12:30	**Closing Remarks**	
13:00	Departure	

15th International Conference on the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

Abstracts of talks

Monday 31.08.2015, 9:00 – 17:50

I1: Monday 31.08.2015,9:00 - 9:40

Path integral Monte Carlo for correlated fermions - can we avoid the sign problem?

Tim Schoof, Simon Groth, Tobias Dornheim and Michael Bonitz,
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My answer will be: "Yes, we can (in some cases)". I will explain this for correlated fermions at finite temperature that are of interest in many fields, including condensed matter, ultracold atoms, dense plasmas and warm dense matter. Path integral Monte Carlo (PIMC) has been the method of choice for an ab-initio description of the thermodynamics. Yet PIMC is hampered by the notorious sign problem that prevents simulations at strong degeneracy. The way to "avoid" it consists in using complementary approaches.

I will first present configuration PIMC - a method that allows for ab-initio simulations exactly at strong degeneracy [1] and yields the most accurate results available for the uniform electron gase at finite temperature [2]. Second, I discuss a novel approach - permutation blocking PIMC [3] – that is capable to dramatically improve the performance of coordinate space approaches.

This work is supported by the Deutsche Forschungsgemeinschaft via SFB-TR24 and grant BO1366/10.

References

[1] T. Schoof M. Bonitz, A. Filinov, D. Hochstuhl, and J.W. Dufty, Contrib. Plasma Phys. 51, 687 (2011)

[2] T. Schoof, S. Groth, J. Vorberger, and M. Bonitz, submitted for publication (2015), arXiv:1502.04616

[3] T. Dornheim, S. Groth, A. Filinov and M. Bonitz, submitted for publication (2015), arXiv:1504.03859

T1: Monday 31.08.2015, 9:40 - 10:00

Ab initio calculation of the ion feature in X-ray Thomson scattering

R. Redmer[1], K.-U. Plagemann[1], H.R. Rüter[1], Th. Bornath[1], M. Shihab[1,2]
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The spectrum of X-ray Thomson scattering is proportional to the dynamic structure factor. An important contribution is the ion feature which describes elastic scattering of X-rays off electrons. We perform molecular dynamics simulations for warm dense beryllium where the forces on the ions are calculated according to the Hellmann-Feynman theorem from the electronic structure for the given ion configuration using Kohn-Sham density functional theory at each time step (DFT-MD method). The simulation runs yield the form factor of bound electrons, the slope of the screening cloud of free electrons and the static ion-ion structure factor. With the DFT-MD method we can calculate the corresponding static ion feature, for the first time, from first principles [1]. Comparison with results for the plasma parameters density and temperature derived from laser-driven X-ray Thomson scattering experiments [2,3] indicates that two-temperature states with $T_e \neq T_i$ have been probed in these setups. Our results will facilitate a better understanding of X-ray scattering in warm dense matter and an accurate measurement of ion temperatures which would allow determining non-equilibrium conditions in shock compression experiments. The *ab initio* method can also be applied to other systems. For instance, warm dense aluminum has been probed recently at the LCLS free electron laser using the seeded X-ray mode which provides the required spectral resolution combined with a high peak brilliance in order to resolve these issues [4].

References

[1] K.-U. Plagemann, H.R. Rüter, Th. Bornath et al., submitted
[2] S.H. Glenzer, O.L. Landen, P. Neumayer et al., *Phys. Rev. Lett.*, 98, 065002 (2007)
[3] H.J. Lee, P. Neumayer, J. Castor et al., *Phys. Rev. Lett.*, 102, 115001 (2009)
[4] L.B. Fletcher, H.J. Lee, T. Döppner et al., *Nature Photonics*, 9, 274 (2015)

T2: Monday 31.08.2015,10:00 - 10:20

The dynamical structure function of strongly coupled binary Coulomb mixtures

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We analyze via theoretical approaches and Molecular Dynamics (MD) simulations the dynamical structure functions $S_{AB}(k,\omega)$ of strongly coupled three-dimensional binary Coulomb systems, for selected density, mass, and charge ratios, both in the liquid and crystalline solid phases. The peaks of $S_{AB}(k,\omega)$ define the collective excitations of the system. Theoretically, the excitations of the liquid phase are described through the quasilocalized charge approximation. Both theory and simulation provide a picture where the longitudinal spectrum is characterized by a pair of low frequency and high frequency plasmon modes and a set of doubly degenerate gapped and acoustic transverse modes [1]. This is in sharp contrast to the mode structure of the weakly coupled regime in which there is one plasmon mode, generated by the sum of the plasma frequencies of the two components, and an “ion-acoustic” mode. We follow the transition in the liquid phase from the weakly correlated to the strongly correlated behavior as Γ, the coupling strength, increases. The strong correlations split the RPA plasmon, generate two longitudinal plasmons, and lift one of the transverse modes. We compare the dynamical structure functions and the collective mode structure with the similar characteristics of a Yukawa plasma [2]. Varying the screening length, one can trace the effect of changing the more customary short range structure to the quite different long range behavior, illustrating the manifestation of the Anderson-Higgs mechanism.

A novel feature identified in MD simulations is the presence of anti-resonances in the dynamical density fluctuation spectra [3], which can be related to, but are distinct from, the well-known Fano effect. The anti-resonance frequencies seem to be coupling independent, but are affected by the nature of damping in the system (i.e. Landau damping, collisional damping, etc).

Supported by NSF and OTKA (grant K-105476).

References

[1] G. J. Kalman *et al* EPL, 107 35001 (2014)
[2] G. J. Kalman *et al* PRE, 87 043103(2013)
[3] L. Silvestri *et al* EPL, 109 15003 (2015)

T3: Monday 31.08.2015,10:20 - 10:40

Quantum simulations of thermodynamic and transport properties of the quark–gluon plasma

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For quantum simulations of thermodynamic and transport properties of the quark–gluon plasma (QGP) within a unified approach, we combine path integral andWigner (phase space) formulations of quantum mechanics [1]. To study thermodynamic properties of a strongly coupled quark-gluon plasma (QGP) the constituent quasiparticles model have been used of. For simulations we have presented the QGP partition function in the form of a color path integral with a new relativistic measure, instead of a Gaussian one used in Feynman and Wiener path integrals. For integration over the color variable we have also developed procedure of sampling the color variables according to the group SU(3) Haar measure. Simulations have been done by the new color path-integral Monte-Carlo method (CPIMC). It is shown that this method is able to reproduce the available quantum lattice chromodynamics (QCD) data and predict the new ones. To study kinetic properties of the QGP the canonically averaged time correlation functions of quantum operators and related kinetic coefficients are calculated according to the Kubo formulas. In this approach the CPIMC is also used to generate initial conditions (equilibrium spatial, momentum, spin, flavor and color quasiparticle configurations) for dynamic trajectories being the solutions of the related differential equations in the color phase space. Correlation functions and kinetic coefficients are calculated as averages of Weyl’s symbols of dynamic operators along these trajectories. Using this approach we have calculated the diffusion coefficient and shear viscosity, which agree well with experimental data obtained at RIHC.

1.V. Filinov, Yu. Ivanov, V. Fortov, M. Bonitz, and P. Levashov. Phys. Rev. C87, 035207 (2013).

T4: Monday 31.08.2015,11:10 - 11:30

Complex Plasmas with Ion Flow: Interaction of Microparticles

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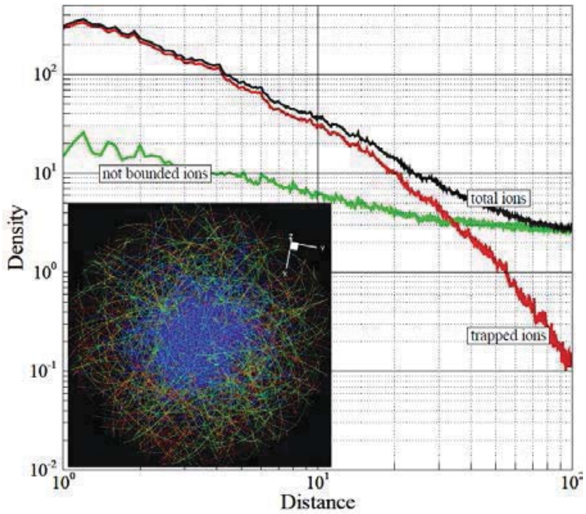
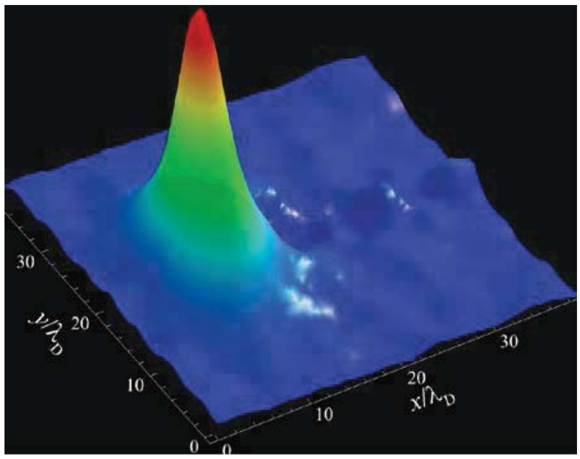
In the present paper we discuss the charging and interaction of microparticles in the near-electrode region of low pressure rf discharge, where the role of external electric field (and the field-associated ion drift) is significant [1, 2]. The interaction is essentially anisotropic and , in particular, may cause an alignment of negatively charged microparticles along the ion flow direction.

The Figure plotted below shows the typical radial distributions of ions (both trapped and untrapped) around micrometer-sized particle (inset shows the typical trapped ion trajectories; the trajectories are color-coded by ion energy) immersed into plasma with ion flow; the cloud of trapped ions, in particular, reduces the charge of the microparticle. Additionally, external electric filed causes polarization of the ion cloud, which in turn, results in dipolar-like interaction of the microparticles and chain-like structure formation.





The detailed molecular dynamics simulations reveal that ion focusing which is responsible, as usually believed, for the formation of the cited chain-like structures, is suppressed significantly under the typical conditions of complex (dusty) plasmas experiments [2]. Finally, our simulations reevaluate an important role of the trapped ions in the formation of string-like structures of microparticles.

The work is supported by Russian Science Foundation Grant No14-50-00124.

References

[1] S.A. Maiorov, S. V. Vladimirov, N. F. Cramer *Phys. Rev. E*, 2000, 63, p 017401–9096.
[2] S.A. Maiorov, Plasma Phys. Rep. 2006, 32 (9), pp. 737 -749.
[3] S.A. Maiorov, B.A.Klumov, Bulletin of the Lebedev Physics Institute, 2013, **40** (10), pp 285-293.

T5: Monday 31.08.2015,11:30 - 11:50

Non-Equilibrium Charge Dynamics in Heterogeneous Systems

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We model dynamics of photo-excitations in functionalized nano-titania of anatase structure. The modeling is performed by reduced density operator method in the basis of Kohn-Sham orbital's. Thermalized lattice vibrations are modeled through ab initio molecular dynamics of nuclei, forming a time-dependent trajectory. Non-adiabatic couplings in the basis of Kohn-Sham orbital's are computed in a course of molecular dynamics, and are utilized to build autocorrelation functions and the Redfield dissipative part of the equation of motion for the reduced density operator. The latter one is solved in the frequency domain (i) and time domain (ii): in the frequency domain, the steady state solution illustrates formation of the density of an excited non-equilibrium state with contributions of multiple electron-hole pairs. Time domain solution for non-equilibrium initial state of the model shows how the energy of photo-excitation is dissipating due to interaction with lattice vibrations with the electron/hole part of an excitation relaxing to the bottom of conduction band /top of valence band. The methodology is applied to titanium dioxide of anatase structure, doped by Ru atom [1] or functionalized by minimalistic Ru nano-cluster [2]. Employed approach is extended on the case of spin-polarized systems such as Co-functionalized titania. In this case charge dynamics of spin-up and spin-down states is studied separately. Solution for nonequilibrium density of electrons is used for determining the dynamics of formation of charge transfer state on the surface, computing surface photo-voltage, and rates of energy and charge transfer. Simulations of these models demonstrate the formation of charge transfer state. These results are of the importance for an optimal design of nano-materials for photo-catalytic water splitting and solar energy harvesting.

References

[1] Inerbaev T., Hoefelmeyer J., and Kilin D., *J. Phys. Chem. C* (2013) **117** 9673–9692.

[2] Huang S., Inerbaev T.M., and Kilin D.S. *J. Phys. Chem. Lett.* (2014) **5** 2823−2829.

T6: Monday 31.08.2015,11:50 - 12:10

What is it dynamical entropy

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The concept of dynamic entropy (D-entropy), proposed in the mechanics of structured particles is discussed. D-entropy is defined as the relative increase in the internal energy of the system due to its motion energy. Comparison of D-entropy with thermodynamic entropy of Clausius, Boltzmann's entropy and Kolmogorov - Sinai entropy is performed. The numerical results calculations of the changes of the systems' D-entropy consisting from the different numbers of elements during their motions into the non-homogeneous space are given. Areas of application D- entropy and the possibility of its use for the analysis of dynamic systems are discussed.

Key words: dynamics, entropy, irreversibility, classical mechanics.

T7: Monday 31.08.2015,12:10 - 12:30

Ion Potential in Stationary Nonequilibrium Warm Dense Matter

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This work is devoted to dense electron-ion plasmas in the warm-dense-matter regime where electrons (ions) are weakly (strongly) correlated and electronic quantum effects are relevant. We concentrated on stationary nonequilibrium states where electrons move relative to the ions—a situation that is ubiquitous in dense plasmas including electron or ion beams, laser accelerated electrons, or ions penetrating a dense quantum plasma or a metal (ion stopping).
To compute the effective dynamically screened ion potential a linear response description of the electrons via the Mermin dielectric function is utilized with electron-electron collisions taken into account via a relaxation time approximation [1, 2]. The ion potential strongly deviates from the static Yukawa potential [3] exhibiting the familiar oscillatory structure with attractive minima. between ions. The results of the investigation show the importance of finite temperature effects even when the electron thermal energy is lower than the Fermi energy. Also, it is found that the collisions have a strong nonlinear effect on the potential distribution around the ion. Finally, we obtain the minimal electron streaming velocity for which attraction between ions occurs. This velocity turns out to be less than the electron Fermi velocity.
The observed effects should be of high relevance for transport under warm dense matter conditions, in particular for laser-matter interaction, electron-ion temperature equilibration and for stopping power. Also, the dynamically screened effective potential can be directly used for MD simulations of classical ions on the background of streaming quantum electrons as discussed in Ref. [4]. This allows to obtain first principle static and dynamic results for the ion component, including the range of strong ion coupling.

References

[1] Zhandos Moldabekov, Patrick Ludwig, Michael Bonitz, Tlekkabul Ramazanov Phys .Rev. E **91**, 023102 (2015)
[2] Zh. A. Moldabekov, P. Ludwig, J.-P. Joost, M. Bonitz, and T. S. Ramazanov, Contrib. Plasma Phys. **55**, 186 (2015)
[3] T. S. Ramazanov, Zh. A. Moldabekov, M. T. Gabdullin, and T. N. Ismagambetova, Phys. Plasmas **21**, 012706 (2014)
[4] P. Ludwig, M. Bonitz, and H. Kahlert, J. Phys.: Conf.Series **220**, 012003 (2010).

I1: Monday 31.08.2015,14:00 - 14:40

Correlation and Quantum Effects in Non-ideal Plasmas

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Dynamic methods of generation of non-ideal plasma at extremely high pressures, based on the compression and heating of matter in intensive shock waves, adiabatic expansion of preliminary compressed matter and quasiisentropic compression are considered. To generate shock waves in the terapascal pressure range the cylindrical and spherical condensed high explosives, laser and corpuscular beams, high velocity impacts, and soft X-rays were used. The highly time-resolved diagnostics of the extreme states of plasma were carried out with laser interferometer, fast acting electro-optical transducers, pyrometers, and high-speed spectrometers equipped with the electron-optical transmission lines. The experimental data obtained and the physical models of behavior of plasma at extremely high pressures, temperatures and deformation rates are discussed. These are the metallization and dielectrization of strongly compressed matter, high energy density thermodynamics and phase transitions, including plasma phase transitions. Shear viscosity of matter as an indicator of particles correlations in a wide region of parameters from Plank's scale to laboratory conditions is analyzed. Wide-range semi-empirical equations of state and models are constructed, which were used for multidimensional numerical simulation of pulsed high-energy processes and description of solar plasma. The role of the quantum and correlation effects in strongly coupled plasma analyzed on the base of the experimental data obtained.

T8: Monday 31.08.2015,14:40 - 15:00

Non-Ideal Plasma and Early Experiments at FAIR

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Early Experiments at FAIR in 2018–2022, suggested by HEDgeHOB collaboration in the field of non-ideal plasma physics, are discussed. Specific energies of 5-10 kJ/g, pressures of 1-2 GPa and temperatures of 1-2 eV are expected to be reached in the substance at the first experiments with the U^{+28} beam with the energy of 0,2 AGeV and maximal intensity $3{\cdot}10^{10}$ per impulse. It will gives possibility to investigate two phase region including critical point of several metals in HIHEX (Heavy Ion Heating and Expansion) experiments with the plane and cylindrical geometry, realizing regimes of quasi-isochoric heating, isentropic expansion and compression when the flow strikes with the target. Analysis of thermal radiation transfer will give information about dynamics of vaporization. Measurements of electrical conductivity and optical properties on supercritical adiabat will give information about insulator to metal transition at these conditions. LAPLAS (Laboratory Planetary Sciences) experiments suggested compression of hydrogen and noble gases at initial cryogenic temperatures up to megabar pressures to investigate possible nonideal plasma phase transitions. Possibilities of stimulated Mach configuration to get megabar pressure range are discussed. Much attention is paid to proton radiography like a main diagnostic for direct measurements of density with high space and time resolution. A worldwide unique high energy proton microscopy facility (PRIOR) will be integrated into the HEDgeHOB beam line at FAIR as an independent diagnostic tool. This will allow employing high energy (3 – 10 GeV), high intensity ($2{\cdot}10^{13}$ per pulse) proton beams for fascinating multidisciplinary research such as experiments on fundamental properties of materials in extreme dynamic environments generated by external drivers (pulsed power drivers, high energy lasers, gas guns or HE generators) prominent for materials research and non-ideal plasma physics. We will consider possibilities of explosively driven technique matched with proton radiography to investigate regions of plasma phase transitions in H_2, D_2, N_2, rare gases, etc. at megabar pressures and reveal the influence of strong Coulomb interaction on thermodynamical properties of non-ideal plasma.

T9: Monday 31.08.2015,15:00 - 15:20

On Kr laser-electric breakdown and discharge plasma dynamics

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Pulsed gas discharge ignition has been investigated extensively. Energy efficiency issues of discharge ignition and sustenance are of great practical interest. Combining different electric field parameters (AC, RF, microwave) and configurations (orthogonal and collinear) is one of problem solution ways.

Experimental investigation of a combined laser-electric (λ~213, 266, 355, 532, 1064 nm, $\tau_{0,5}$~18 ns, I_0~10^9–10^{11} W/cm^2; E_{DC}~0–13,2 kV/cm) breakdown in krypton at sub-atmospheric pressures (p~10^1–10^5 Pa) has been performed. Breakdown thresholds were evaluated at different gas pressures and irradiation wavelengths for 50% breakdown probability in terms of laser and electric components. It has been discovered that such a combined breakdown could take place at laser and electric components values significantly less than those for ‘pure’ optical or electric impact. Laser beam was orthogonal to electric field.

Discharge in Kr is less investigated that in other noble gases, despite it has good perspectives as an alternative to Xe in light sources. We defined thresholds of laser I_{opt} and electric E_{el} breakdown first and then used them as a reference for combined breakdown components dimensionless analysis ($i=I/I_{opt}$, $u=E/E_{el}$). The effect of gas pressure and radiation wavelength on combined breakdown threshold components was inversely proportional due to recombination probability decrease, multi-photon probability and electron acceleration rate increase as p and λ are reduced. In addition to often used electric, laser, laser-assisted electric and electric-assisted laser breakdown regimes we discovered a new synergistic combined one and evaluated it’s borders.

To find out nature of this combined regime we also investigated discharge dynamics focusing on photoelectron and thermionic emission, multi-photon ionization and electron tunneling effects, laser and arc induced shock waves at different impact conditions. One of findings was that i to u ratio influences discharge dynamics and macrostructure due to laser-induced plasma and shockwave interference with an arc, in case of high u that led to formation of a μs-order lifetime compressed radiating filament along laser axis.

This work was performed at the facility “Beam-M” (RFMEFI59014X0001), supported by the State Task of the Russian Ministry of Education and Science, and the Russian Foundation for Basic Research (grants 13-08-01391 and 14-08-01087).

T10: Monday 31.08.2015,15:20 - 15:40

Permutation blocking path integral Monte Carlo simulations of strongly degenerate non-ideal fermions

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The ab initio simulation of strongly degenerate non-ideal fermions is of high current importance for many fields, including electrons in a quantum dot, the homogeneous electron gas and dense two-component plasmas in stellar interiors and modern laser compression experiments (warm dense matter).
We present a novel approach [1] to path integral Monte Carlo (PIMC) simulations of strongly degenerate correlated fermions at finite temperature by combining a fourth-order factorization of the density matrix [2] with antisymmetric propagators, i.e., determinants, between all imaginary time slices. To efficiently run through the modified configuration space, we introduce a modification of the widely used continuous space worm algorithm [3], which allows for an efficient sampling at arbitrary system parameters. To benchmark the capability of our method regarding the simulation of degenerate fermions, we consider multiple electrons in a quantum dot and compare our results with other ab initio techniques (standard PIMC and CPIMC [4]), where they are available. The present permutation blocking path integral Monte Carlo approach allows us to obtain accurate results even for N=20 electrons at low temperature and arbitrary coupling, where no other ab initio results have been reported, so far.

References

[1] T. Dornheim, S. Groth, A. Filinov and M. Bonitz *submitted for publication*, 2015
[2] K. Sakkos, J. Casulleras and J. Boronat *J. Chem. Phys.*, 2009, 130 (204109)
[3] M. Boninsegni, N.V. Prokov'ev and B.V. Svistunov *Phys. Rev. E*, 2006, 74 (036701)
[4] T. Schoof, M. Bonitz, A.V. Filinov, D. Hochstuhl and J.W. Dufty, *Contrib. Plasma Phys.*, 2011, 51 (687-697)

T11: Monday 31.08.2015,16:10 - 16:30

The Dynamics of Dust Structures under Magnetic Field in Stratified Glow Discharge

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The experimentally observed complex behavior with an inversion of the angular velocity of rotation of complex plasma in a stratified discharge in a magnetic field [1,2] is inherent not only for the glow discharge plasma, but also for other types of discharges [3,4].
The complexity of the behavior of dust structures is determined by the presence of many factors simultaneously affecting to the dynamics of complex plasma. One of the interesting aspects of the study of the dynamics of dust structures in a glow discharge is its connection with the kinetic processes in the plasma, as for electrons as well as for ions [5,6].
We used methods of diagnosing these processes which reflect this connection through the study of the dynamics of dust structures in a magnetic field. In the experiment it was observed the existents of kinetic effects, the eddy current in the strata and the increase in the rate of ion flow in gas mixtures that significantly affect the dynamics of plasma-dust structures.
Work is supported by RSF N.14-12-00094

References

[1] V.Yu. Karasev, E.S. Dzlieva, A.Yu. Ivanov et al., *Phys. Rev. E,* 2006 74, p. 066403.
[2] Vasiliev M.M., D'yachkov L. G., Antipov S. N., Huijink R., Petrov O.F., Fortov V.E., *Europhys. Lett.* 2011, 93, p. 15001.
[3] U.Konopka, D.Samsonov, A.V.Ivlev, J.Goree, V.Steinberg, G.E.Morfill, *Phys. Rev. E,* 2000, 61, p. 1890.
[4] J. Carstensen, F. Greiner, L.J. Hou, H. Maurer, A. Piel, *Physics of Plasmas*, 2009, 16, p. 013702.
[5] A.V. Nedospasov, *Phys. Rev. E,* 2009, 79, p. 036401.
[6] S.A. Maiorov, T.S. Ramasanov, K.N. Dzhumagulova, *Phys. Plasm*, 2008 15, p. 093701.

T12: Monday 31.08.2015,16:30 - 16:50

Voids in dusty plasma of a stratified DC glow discharge

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The experimental investigations of the dusty plasma parameters of a DC glow discharge were performed in laboratory conditions. In the strong electric field of a stratified positive column in a vertically oriented discharge tube the clouds of dust particles levitated. Under some conditions the dust free regions (voids) were formed in the center of the dust particles clouds (i.e. at the axis of the discharge tube).

A model for the positive column of a DC glow discharge in inert gases with dust particles is presented. The model is based on the previously developed model [1,2] with the dust particles motion sub-model. The non-local Boltzmann equation for the electron energy distribution function, drift-diffusion equations for ions and dust particles, and the Poisson equation for electric field were calculated self-consistently. The electrostatic force confining the dust clouds at the axis of the discharge tube, the ion drag force acting on dust particles towards the discharge tube wall, the inter-particle repulsive force were taken into account.

The behavior of voids formation was investigated for different discharge conditions (sort of gas, discharge pressure and discharge current) and dust particles parameters (particles radii and particles total number). The radial distributions of dusty plasma parameters in a dust cloud were calculated for different experimental conditions. It was shown that it is the ion drag force radial component that leads to the voids formation. Both experimental and calculated results show that the higher the discharge current the wider dust-free region (void) is formed. The calculations also show that more pronounced voids are formed for dust particles with larger radii and under lower gas pressures.

References

[1] G.I. Sukhinin, A.V. Fedoseev, S.N. Antipov, O.F. Petrov, V.E. Fortov, *Phys. Rev. E*, 2013, 87, 013101

[2] G.I. Sukhinin, A.V. Fedoseev, M.V. Salnikov, S.N. Antipov, O.F. Petrov, V.E. Fortov, *EPL*, 2013, 103, 35001

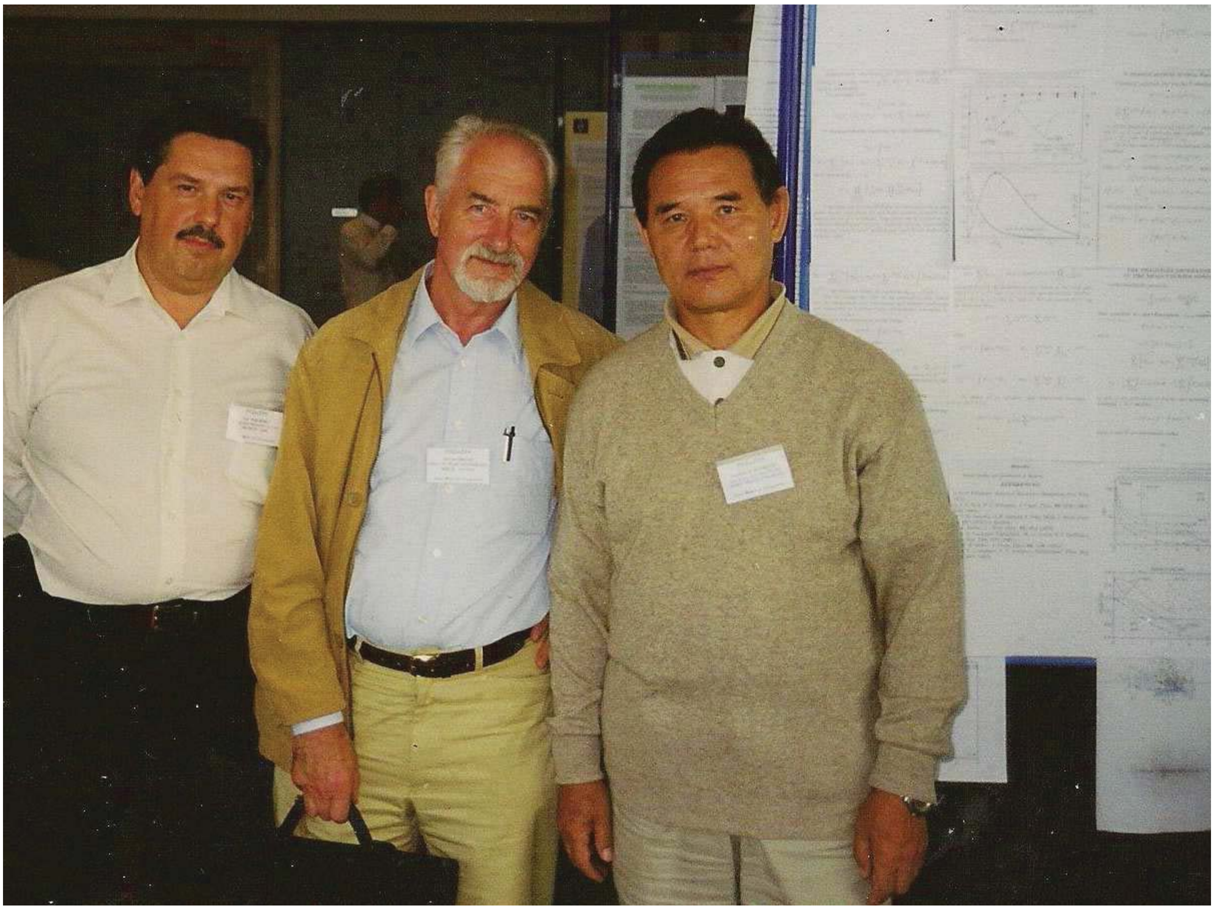
In remembrance of Professor Fazylkhan Baimbetov from the community of nonideal plasma research

It was a great shock for our community when whe learned that on 24th of April this year 2014 our friend Fazylkhan Baimbetov passed away. Since a quarter of a century he was one of the most active members of our community. I cannot tell you exactly, when he appeared first at the series of International Conferences on the Physics of Nonideal Plasmas (PNP), but my subjective impression is now, that he was always present, with his always active participation, his steady optimism, his friendly smile. We met always with great sympathy and discussed in Russian the latest problems and achievements in the physics of Nonideal Plasmas. In particular we discussed the Bogoliubov hierarchy for distribution functions and effective potential methods, which played a central role for both of us. Due to his constant efforts and the growing number of his collaborators participating in the Nonideal Plasma Conferences, Fazylkhan got a high reputation in the community.

In 2003 I had the great pleasure and honor to be invited by Al-Farabi Kazakh National State University, where he served already since 20 years. I learned that the people working there met him with deep respect as a colleague and leader who was very much involved in teaching and education, he annually had 800-900 hours of lectural and practical load, but continued actively his scientific work in the field of the kinetic theory of rarefied turbulent plasma, dense gases and non-ideal plasma. I had the great honor to be invited to his house in a suburb of Almaty and spend a very nice evening with him, his family and his friends. I will forever remember this evening which gave me the best impression how happy he lived in his private community of family, relatives and friends. Among the highlights I remember an infinite number of toasts on ever friendship and that I had to eat the eyes of mutton. On next day Fazylkhan came already with a draft of a common paper which he possibly invented still in that night. In my files I still have that draft “INTERPARTICLE INTERACTIONS AND TYHERMODYNAMICS OF PARTIALLY IONIZED HYDROGEN PLASMAS” by Yu.V. Arkhipov, F.B. Baimbetov, A.E. Davletov, and W. Ebeling. By some reason, mainly his and my health problems, we never succeeded to finish the work and to prepare it for publication But I still remember and enjoy the very nice collaboration with Fazylkhan and his group.

In conclusion let me express my deep regret, that a year before the nonideal plasma community will come to meet at his place Almaty, Fazykhan passed away, missing this way the chance to see personally the deep respect the international community developed for this outstanding Kazakh scientist and his Kazakhian school. We will not forget him and his remarkable scientific contribution to our field.

Werner Ebeling



Fazylkhan Baimbetov (right) with Igor Tkachenko (left) and this author on the PNP-Conference in Valencia 2003.

15th International Conference on
the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

Abstracts of talks

Tuesday 01.09.2015, 9:00 – 17:10

I3: Tuesday 01.09.2015, 9:00 - 9:40

Time-dependent Density Functional Theory to Compute Response Properties of Warm Dense Matter and Non-Ideal Plasmas

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There is a need to simulate dynamic material response properties under shock conditions where experimental data is often limited due to the extreme scales involved (MBars, 1000s of K, and 4 times compressed solid densities). Knowledge of material properties at these conditions is a vital element of simulations of planetary collisions, inertial confinement fusion experiments, and the surfaces of some stars. Considerable progress has been made using density functional molecular dynamics (DFT-MD) to model thermodynamic properties of material under these conditions; however, the approach is limited to cases in which the electrons are constrained to an ideal thermodynamic distribution. We will describe the development and use of Ehrenfest Time-dependent density functional theory (TDDFT) [1] to evolve coupled electron-nuclear dynamics in non-ideal plasmas and warm dense matter [2]. This work allows the simulation of many materials previously hard to simulate properties and in particular the direct calculation of x-ray response of warm dense matter without making a bound-free decomposition. We will compare our findings on Beryllium and Aluminum to recent experiments [3] and simulations [4,5]. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Security Administration under contract DE-AC04-94AL85000.

References

[1] E. Runge and E. K. U. Gross, 1984, 52, pp 997-1000.
[2] A.D. Baczewski, L.Shulenburger, M.P. Desjarlais, and R.J. Magyar, 2014, SAND-report 2014-0597, pp 1-58.
[3] L.B. Fletcher, H.J. Lee, T. Döppner, E. Galtier, B. Nagler, P. Heimann, C. Fortmann, S. LePape, T. Ma, M. Millot, A. Pak, D. Turnbull, D.A. Chapman, D.O. Gericke, J. Vorberger, T. White, G. Gregori, M. Wei, B. Barbrel, R.W. Falcone, C.C. Kao, H. Nuhn, J. Welch, U. Zastrau, P. Neumayer, J.B. Hastings, and S.H. Glenzer, 2015, Nature Photonics, pp 1749-4893.
[4] K-U. Plagemann, P. Sperling, R. Thiele, M.P. Desjarlais, C. Fortmann, and T. Döppner, New Journal of Physics, 2012, 5, pg. 55020.
[5] A.N. Souza, D.J. Perkins, C.E. Starrett, D. Saumon, and S.B. Hansen, Physical Review E, 2014, 89, pg 23108.

T13: Tuesday 01.09.2015, 9:40 - 10:00

WDM-Diagnostics Using K-Line Emission Profiles of Ar

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K-line profiles emitted from a warm dense plasma environment are used to determine plasma parameters and the time-integrated charge state distribution of Ar droplet plasmas created by laser pulses of several Joule energy at intensities of 10^19 W/cm^2 [1].

Applying a quantum statistical perturbation approach, we infer temperature gradients within the Ar droplet from cold temperatures of the order of some 10 eV up to higher temperatures of some 100 eV at bulk electron densities.

First we calculate unperturbed wave functions, ionization, binding as well as emission energies using a chemical ab initio code. Then we consider the plasma screening as a perturbation to the many-particle-Hamiltonian obtaining energy shifts due to electron-ion and electron-electron interaction [2].

Further, the charge state distribution and ionization degree are calculated using up to 15 coupled Saha-like equations. Here, the internal partition functions of electrons and ions account for particle interactions [3].
We observe several Mott transitions in solid density Argon at temperatures below 50 eV which leads to a high degree of ionization at rather low plasma temperatures.

According to our approach we get a good reproduction of spectral features that are strongly influenced by ionization and excitation processes within the plasma. We compare our results with the widely known FLYCHK code [4]. It is found that different results for the inferred temperature distribution can be accounted for by internal degrees of freedom (bound states) as well as treating pressure ionization quantum statistically.

References

[1] P. Neumayer, B. Aurand, R. A. Costa Fraga, et al., Phys. Plasmas 19 (2012) 122708.

[2] A. Sengebusch, H. Reinholz, G. Röpke, U. Zastrau, et al., J. Phys. A: Math. Theor 42 (2009) 214061.

[3] D. Kremp, W.-D. Kraeft, et al., Quantum Statistics of Nonideal Plasmas, Springer Berlin, 2005.

[4] H.-K. Chung, M. Chen, W. Morgan, Y. Ralchenko, R. Lee, HEDP 1 (2005) 3.

T14: Tuesday 01.09.2015,10:00 - 10:20

Dynamic structure factor of Yukawa one-component plasmas

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The approach based on the classical method of moments is applied to a Yukawa one-component plasma, i.e. a system of charged particles on a neutralizing background that interact via the Yukawa potential. The interest to such systems has arisen in the context of dusty plasmas [1].

The method of moments (see [2, 3] and references therein) permits to reconstruct the dynamic characteristics of systems at thermal equilibrium in the class of Nevanlinna functions, e.g., to restore the dynamic structure factor (DSF) in terms of its few power moments. The advantage of such an approach is that those power moments can be independently calculated for any model potential by employing the Kubo linear response theory and the static structure factor obtained from the Ornstein-Zernike relation in the hyper-netted chain approximation. At the same time there is a drawback in the approach since it contains a phenomenologically unknown parameter function with some specific mathematical properties, which is then called the Nevanlinna parameter function (NPF). It is well known that the simplest way to resolve above stated difficulty is to model the NPF as a purely imaginary function of the wavenumber and thermodynamic parameters [4].

A novel technique is developed herein to express the NPF in terms of the Yukawa plasma static parameters, i.e. the coupling parameter, the Yukawa potential screening length, and the wavenumber. A good agreement is achieved for on the DSF between the present results (that automatically satisfy the first five sum rules) and the molecular-dynamics data of [5].

References

[1] Z. Donkó, G.J. Kalman, P. Hartmann, *J. Phys.: Condens. Matter*, 2008, 20, 41310.
[2] I. M. Tkachenko, Y. V. Arkhipov, and A. Askaruly, The Method of Moments and its Applications in Plasma Physics (Lambert, Saarbrücken, 2012).
[3] Yu.V. Arkhipov *et al.*, *Phys. Rev. E*, 2014, 90, 053102; *Phys. Rev. E*, 2014, 91, 019903.
[4] V.M. Adamyan, T. Meyer, I.M. Tkachenko, *Sov. J. Plasma Phys.*, 1985, 11, 481; T. Meyer, I.M. Tkachenko, *Contrib. Plasma Phys.*, 1985, 25, 437.
[5] J.P. Mithen *et al.*, *Phys. Rev. E*, 2011, 84, 046401.

T15: Tuesday 01.09.2015,10:20 - 10:40

Internal Energy of the Classical Two- and Three-Dimensional One-Component-Plasma

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The one-component-plasma (OCP) is an idealized system of identical point-like charged particles immersed in a uniform neutralizing background of opposite charge. This model is of considerable interest from the fundamental point of view and has wide interdisciplinary applications. Although thermodynamic properties of the OCP have been extensively studied over decades, simple physically motivated approaches are still of considerable interest. The purpose of this paper is to discuss a simple approach to estimate the internal energy of two-dimensional (2D) and three-dimensional (3D) classical OCP in a wide parameter regime.

The one-component-plasma with the uniform background is characterized by the particle charge Q, particle density n, and the temperature T. The electrical potential around a single particle obeys the corresponding Poisson equation. In two dimensions, the interaction is logarithmic, $\varphi = - Q\ln(r/a)$. Here a is the 2D Wigner-Seitz radius. The coupling parameter in 2D, $\Gamma = Q^2/T$, does not depend on the particle density. In three dimensions the potential is of conventional Coulomb type, $\varphi = Q/r$. Interparticle coupling is then characterized by the coupling parameter $\Gamma = Q^2/aT$. As Γ increases, the OCP shows a transition from a weakly coupled gaseous regime ($\Gamma \ll 1$) to a strongly coupled fluid regime ($\Gamma \gg 1$) and crystallizes into the triangular lattice near $\Gamma \simeq 135 - 140$ (2D) or into the body-centered cubic lattice near $\Gamma \simeq 170 - 175$ (3D).

Monte Carlo (MC) and molecular dynamics (MD) simulations have been used extensively to obtain the OCP internal energy and equation of state in a very wide range of Γ. There has been a considerable continuous interest in deriving physically motivated analytical estimates or bounds on the internal energy (and other related thermodynamic quantities) of the OCP. It was demonstrated that the internal energy of the OCP is bounded below by the Debye-Hückel (DH) value. This bound is a reasonable measure of the actual energy at weak coupling. To improve the DH theory at moderate coupling a simple modification called “DH+hole” (DHH), based on the recognition that the exponential particle density must be truncated close to the test particles, so as not to become negative, was proposed. At strong coupling, rather good estimate of the OCP internal energy is provided by the ion disc model (IDM) in 2D and by the ion sphere model (ISM) in 3D. In this paper we discuss yet another simple scheme to estimate the OCP internal energy, which is based on the hybrid DHH+(IDM or ISM) consideration. This scheme produces expressions, which reduce to the DH result at weak coupling and to the IDM or ISM result at strong coupling and provides reasonable interpolation between these limits. Since the DHH and ISM approaches can be relatively easily generalized to the case of Yukawa systems, present results can possibly find applications beyond OCP.

This study was partially supported by the Russian Science Foundation, Project No. 14-12-01235.

T16: Tuesday 01.09.2015,11:10 - 11:30

THE DYNAMICS OF DUST PARTICLES IN THE PLASMA AFTERGLOW

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Since it was discovered that dust grains can preserve their residual charge in the post discharge phase, the dynamics of dust grain in the plasma afterglow have been actively investigated by many authors [1–3]. In this paper, the effect of an external direct current (DC) electric field on the dynamics of negatively charged dust particles in the afterglow of dusty plasma has been studied.

Dusty plasma was created in a capacitively coupled 5.28 MHz discharge operated between two plane-parallel electrodes separated by a distance of 21 mm [3]. Ambient air at a pressure of 40 and 99.3 Pa was used as a working gas. Polydisperse Al_2O_3 grains (r_p~ 0.1–10 μm) were illuminated by a narrow laser sheet in the plane perpendicular to the electrode surface. A positive polarity DC voltage was applied to the top electrode simultaneously with rf voltage switching off. The DC electric field strength between the electrodes was estimated as E=1760 V/m). It was found that, after the rf power was switched off, dust grains with radii of 0.1–0.25 μm preserved a residual charge with the value varying between −1e to −10e. The dynamic parameters of dust particles were estimated from the balance of forces acting on the dust grain in the post-discharge phase. The velocity of 0.25 μm grains as a function of gas pressure for two E =1000 and 2000 V/m is shown in Fig. 1. At a gas pressure of 93.3 Pa and the electric field strength of 2000 V/m, we obtained a velocity value of ~2 mm/s for the grains with the size of 0.25 μm which agrees with the experimental data.

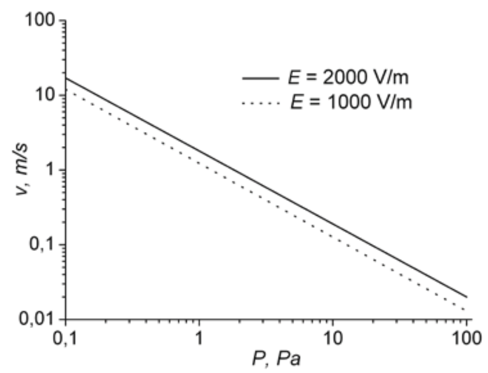

Fig.1. Dust grain velocity in the plasma afterglow in dependence on gas pressure

Acknowledgements

This work is partly supported by State Committee on Science and Technology of the Republic of Belarus and the BRFFR under the grant No Ф14КА3-004.

References

[1] S. Khrapak, et al. *Phys. Rev. Lett.* 2003, 90, p 225002.
[2] L.Couëdel, et al. *Phys. Plasmas.*, 2008, 15, p 063705.
[3] I.I. Filatova, et al. *Plasma Phys. Rep.*, 2011, 37 (12), pp 1042–1045.
[4] L. Wörner et al. *Phys. Plasmas.*, 2013, 20, p 123702.

T17: Tuesday 01.09.2015,11:30 - 11:50

Thermoelectric transport coefficients for warm dense matter including electron-electron collisions

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We present an approach that can resolve the controversy with respect to the role of electron-electron collisions in calculating the dynamic conductivity of dense plasmas. In particular, the dc conductivity is analyzed in the low-density, nondegenerate limit where the Spitzer theory is valid and electron-electron collisions lead to the well-known reduction in comparison to the result considering only electron-ion collisions (Lorentz model). With increasing degeneracy, the contribution of electron-electron collisions to the dc conductivity is decreasing and can be neglected for the liquid metal domain where the Ziman theory is applicable. We give general expressions and respective Pade approximations for the effect of electron-electron collisions in calculating the conductivity in the warm dense matter region, i.e., for strongly coupled Coulomb systems at arbitrary degeneracy [1].

Different expressions for the Coulomb logarithm are discussed in order to consider strong collisions as well. Subsequently, an improved version of an interpolation formula is presented. In addition to the dc-conductivity, other static properties (thermoelectric transport coefficients) as well as the optical conductivity are considered.

References

[1] H. Reinholz, G. Röpke, S. Rosmej, and R. Redmer *Phys. Rev. E.*, 2015, in press.

T18: Tuesday 01.09.2015,11:50 - 12:10

High pressure phase diagram of MgO and FeO

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The state of matter (e.g. temperatures and pressures) inside super-Earths, i.e., planets in the mass range 1-10 M_E, is much more extreme than in the interior of the Earth so that current experiments are not able to cover the whole density-temperature range directly [1]. In order to improve the understanding of the interior of exoplanets and their physical properties [2], *ab inito* calculations for the planetary materials are needed.

Typical representatives are MgO and FeO, which are abundant materials in the Earth's mantle. Both are expected to be also important for the mantle of exoplanets as well as for the rocky cores of gas giants such as Jupiter [3]. Using *ab initio* molecular dynamic simulations (VASP [4]), we have determined the phase diagram for MgO up to 20000 K and 1.5 TPa. In particular, the transition from the solid to the molten salt has been studied using diffusion analyses and pair distribution functions. The transition from the NaCl (B1) to the CsCl (B2) structure in solid MgO is determined by calculating the respective free enthalpies. The phase diagram of MgO is constructed based on the accurate equation of state (EOS) data. We compare with experimental results from (decaying) shock and ramp compression experiments [5, 6]. The B1-B2 and the liquid-solid transition line are compared with earlier simulation and experimental results [7].

The more complex phase diagram of FeO is under investigation, first results show agreement with experimental results for the anti-ferromagnetic system of the B1 phase. Using the quasi-harmonic approximation the EOS is calculated and compared against available experimental data [8].

References

[1] D. Valencia, R.J. O'Connell and D. Sasselov, Icarus 181, 545 (2006).

[2] V. Stamenkovic, D. Breuer and T. Spohn, Icarus 216, 2 (2011).

[3] G. Kresse and J. Hafner, Phys. Rev. B 48, 13115 (1993).

[4] F.H. Wilson and B. Militzer, Phys. Rev. Lett., 108, 111101 (2012).

[5] R.S. McWilliams, D.K. Spaulding, J.H. Eggert et al., Science, 338, 1330 (2012).

[6] F. Coppari, R.F. Smith, J.H. Eggert et al., Nature Geoscience, 6, 926 (2013).

[7] D. Cebulla and R. Redmer, Phys. Rev. B, 89, 134107 (2014).

[8] R.A. Fischer, A.J. Campbell, O.T. Lord et al., Geophys. Res. Lett. 38, (2011).

T19: Tuesday 01.09.2015,12:10 - 12:30

The method of plasma diagnostics by measuring the dust-free region near the electric probe

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The usage of the traditional electric probe method in diagnostics of the gas discharge dusty plasmas parameters causes an interesting behavior of the plasma-dust formations as well as of the individual dust particle near probe region [1]. Thus, various trajectories of dust particles [2] and the dust-free region around the probe in a glow discharge have been observed and analyzed [3].

In this work the method for determination of the temperature and concentration of the buffer plasma on the basis of the experimental measurement of the radius of the dust-free region around an electrical probe in a dusty plasma in the positive column of a glow discharge is presented. The size of the dust-free region depending on the potential applied to the probe and the discharge plasma parameters were investigated. To determine the parameters of the plasma the energy balance between dust particles and probe field was used [4]. The main characteristics of the buffer plasma, such as temperature and concentration of electrons were determined under different experimental conditions based on proposed method.

References

[1] T.S. Ramazanov, S. K. Kodanova, O.F. Petrov, S.N. Antipov, K.N. Dzhumagulova, M K Dosbolayev and A N Jumabekov, *J. Phys. A: Math. Theor.*, **42**, 214026 (2009)
[2] T.S. Ramazanov, N. Kh. Bastykova, Y.A. Ussenov, S.K. Kodanova, K.N. Dzhumagulova, and M. K. Dosbolayev, *Contrib. Plasma Phys.*, **52**, No.2 (2012)
[3] K. N. Dzhumagulova, T. S. Ramazanov, Y. A.Ussenov, M. K. Dosbolayev, and R.U. Masheeva.*Contrib. Plasma Phys.* **53**, No. 4-5, 419 – 425 (2013)
[4] Y. A. Ussenov, T. S. Ramazanov, K. N. Dzhumagulova and M. K. Dosbolayev, EPL **105** 15002 (2014)

I4: Tuesday 01.09.2015,14:00 - 14:40

Non-Congruent Phase Transitions in Non-Ideal Coulomb Systems

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Non-congruent (or *incongruent*) phase transitions (NCPT) are under discussion as the general form of 1st-order phase transformations in complex non-ideal systems with two or more globally conserved "charges" e.g. in systems with two or more chemical elements in terrestrial chemically reacting non-ideal plasmas [1] or in more complicated gas-liquid-like and deconfinement phase transitions (PT) in asymmetric ultra-dense nuclear matter (relevant for heavy-ion collisions and neutron stars) [2,3] etc. The key role of Gibbs-Guggenheim conditions for correct description of non-congruence is emphasized. Interrelation of non-congruence with the basic feature of phase interfaces in Coulomb systems – average electrostatic potential drop (Galvani potential) – is discussed and emphasized too. A modified version for the model of Binary Ionic Mixture on uniformly compressible electron-gas background (BIM(~) [4]) is used as the most simple and transparent realization of NCPT in non-ideal Coulomb systems. Features of this simplest variant of a NCPT (e.g., dimensionality and topology of phase diagrams, properties and location of critical and end points *etc*.) are compared with NCPT in chemically reacting plasmas, on one side, and on the other side with the NCPT in nuclear liquid-gas PT and in the deconfinement PT at high density matter in extreme conditions. We discuss hypothetical non-congruence of ionization- and dissociation-driven PTs in typical planetary mixtures and NCPT for high-*T* evaporation in chemical compounds like oxides, hydrates, molten salts *etc* [5]. We discuss also hypothetical non-congruence in simplified three-component model of complex (dusty and colloid) plasmas of macro- and micro-ions and electrons.

This work was supported by Russian Scientific Fund, Grant No: 14-50-00124.

References

[1] I. Iosilevskiy, V. Gryaznov, E. Yakub, C. Ronchi, V. Fortov *Contrib. Plasma Phys.*, 2003, **43**, pp 316-320.
[2] I. Iosilevskiy *Acta Physica Polonica B* (*Proc. Suppl.*) 2010, **3**, pp 589-600.
[3] M. Hempel, V. Dexheimer, S. Schramm and I. Iosilevskiy *Phys. Rev. C,* 2013, **88**, pp 014906 (26).
[4] I. Iosilevskiy, A. Chigvintsev *Journal de Physique IV,* 2000, **10**, Pr5, pp 451-454.
[5] I. Iosilevskiy, V. Gryaznov, A. Solov'ev *High Temp.-High Pressure*, 2014, **43**, pp 227-241.

T20: Tuesday 01.09.2015,14:40 - 15:00

Free energy model for the high pressure solid phases of carbon

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Carbon plays an important role for the chemistry and physics of planets. In Neptune and Uranus for expample the abundance of carbon in the form of methane amounts to 10-15% of the total mass. Methane can dissociate under the extreme conditions in the interior of these planets and may precipitate in the form of diamond [1].
It was suggested that carbon can also be a major constitutent in extrasolar planets like the super-Earth 55 cancri e, which has been discussed to contain 10-70% of carbon [2] in diamond phase.
The modeling of the interior structure of such planets requires precise knowledge of the phase diagram and equation of state (EOS) of carbon for a wide range of pressures and temperatures. A variety of high pressure phases has been proposed, including a body centered cubic phase with eight atoms in the unit cell (BC8) above 1 TPa, followed by a simple cubic (SC) phase above 2.9 TPa [3]. Both phases have yet to be confirmed experimentally.
In our work, we calculate a free energy model [4] for the diamond, BC8 and SC phases using the Vienna Ab Initio Simulation Package (VASP [5]), which is based on molecular dynamics for the ions and density functional theory for the electrons. This allows us to include anharmonic effects in the EOS. We investigate the diamond-BC8 and BC8-SC coexistence lines for temperatures up to 8000 K and compare with other theoretical predictions [6,7]. We also apply a thermodynamically constrained correction [8] to the EOS which brings our data in line with experimental results for low pressures.

References

[1] M. Ross, Nature **292**, 435 (1981)
[2] N. Madhusudhan, K.K.M. Lee, and O. Mousis, Astrophys. J. Lett. **759**(2), L40 (2012)
[3] M. Martinez-Canales and C.J. Pickard, Phys. Rev. Lett. **108**, 045704 (2012)
[4] M. French and R. Redmer, Phys. Rev. B **91**, 014308 (2015)
[5] G. Kresse and J. Hafner, Phys. Rev. B **48**, 17 (1993)
[6] A.A. Correa, L.X. Benedict, D.A. Young, E. Schwegler, and S.A. Bonev, Phys. Rev. B **78**, 024101 (2008)
[7] L.X. Benedict, K.P. Driver, S. Hamel, B. Militzer, T. Qi, A.A. Correa, A. Saul and E. Schwegler, Phys. Rev. B **89**, 224109 (2014)
[8] M. French and T.R. Mattson, J. Appl. Phys. **116**, 013510 (2014)

T21: Tuesday 01.09.2015,15:00 - 15:20

Configuration Path Integral Monte Carlo Simulation of Non-Ideal Fermions

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The ab initio simulation of weakly to moderately degenrate ele ctrons is of high relevance for the understanding of warm dense matter, e.g. electrons in metals, quantum dots, laser fusion experiments as well as dense plasmas in compact stars or planet cores.
Based on first principles, the Configuration PIMC approach (CPIMC) allows for the exact computation of thermodynamic properties of strongly degenerate fermionic many-body systems with arbitrary pair-interactions [1,2]. Due to the fermion sign problem, CPIMC is feasible only for weakly interatcing systems. Here, further developments of the CPIMC method are presented which extend the accessible region to the moderately coupled regime. Results for the homogeneous electron gas and 2D quantum dots are presented and compared to other methods.

References

[1] T. Schoof, M. Bonitz, A. Filinov and J. Dufty, *Plasma Phys.*, 2011, 51, pp 687.
[2] T. Schoof, S. Groth, J. Vorberger and M. Bonitz arxiv: 1502 .04616, submitted to PRL
[3] D.M. Ceperley, *Rev. Mod. Phys.*, 1995, 65, pp 279

T22: Tuesday 01.09.2015,15:20 - 15:40

Theory of electrostatic probe in dusty plasma, generated by a volume source of fission fragments

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In the present paper the theory of electrostatic probe in nuclear induced dusty plasma is regarded. Electric probe is used as a primary diagnostic tool in the measurement of the local parameters of the ionized gas in a variety of media [1], such as the field of electrical discharge and afterglow, the ionization region behind the shock waves, flames, MHD generators, plasma jet, as well as atmospheric and space plasmas. Despite its limited area of application techniques probe measurements and successful development in recent years, non-contact diagnostic methods (optical, including laser and microwave), interest in the use of electric probes unabated, as the improvement of the experimental apparatus and measurement technique helps transform probe technique almost the only means to study the local properties of the plasma. Electric probe representing substantially a metal electrode placed in the plasma apparatus is relatively simple, however, the theory 1 of electrical probes complicated by the fact that the probes are boundary surface with respect to the plasma, and the equations describing the behavior of the plasma near the interface are nonlinear [2].

The grains are equally small by their mass and size. The charging process in the plasma is limited by interaction of dust grains and electrons by quasineutrality condition and total gains charge is equal to $Z = 3kTer_0/(2e^2)$ and reaches its maximum values up to 104 *e* [3]. We also define the ratio of electrons concentration and positive ions concentration in the undisturbed region by the probe field as $\delta = n_e/n$.

The nuclear induced plasma in the core of nuclear reactor by the the following nuclear reactions $^3He + n \rightarrow p + T + 0.76$ *Mev*. In the present paper the theoretical analysis developed to the detailed explanations of the probe diagnostics technique of negative grains in plasma mixtures like ^3He + DG where the electrons and negative grains are presented in unknown proportion.

References

[1] R.H. Huddlestone and S.L. Leonard, Plasma Diagnostics Techniques, Academic Press, New York-London, 1965.
[2]. P.M. Chung, L. Talbot, K.J. Touryan, Electric probes in stationary and flowing plasmas: Theory and Application, New York, 1975.
[3] P.K. Shukla, A survey of dusty plasma physics, Physics of Plasmas, vol.8, number 5, May 2001, pp.1791-1802.

T23: Tuesday 01.09.2015,16:10 - 16:30

Thermodynamics of dynamically compressed gases at megabar pressure range

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The thermodynamic properties of hydrogen and noble gases at high pressures and temperatures are of interest because they are widespread in nature and are used in various high energy facilities, as well as because of active investigations of processes inside the giant planets and so called extrasolar planets. The equation of state of hydrogen (deuterium) and noble gases submegabar and megabar ranges of pressures were experimentally studied with different methods. The thermodynamic properties of noble gases in the megabar pressure range, where a high density of matter is accompanied by a strong Coulomb interaction (strongly non-ideal plasma) were theoretically described both within the quasichemical concept (free energy model) and within the ab-initio methods involving the direct numerical simulation of system of nuclei and electrons. In spite of experimental and theoretical achievements in this range of parameters further study of dynamically compressed gases is important. In particular, the problem of the possibility of a phase transitions at high compression degrees is not resolved yet. The experimental data on caloric and thermal equation of state cover pressures of shock and isentropic compression from kilobars to dozen megabars and densities three times higher than aluminum density. Last several years new theoretic results in frames of chemical picture and ab-initio methods in a wide range of shock pressures have been presented as well.

Here we present the results of calculation of principal Hugoniots for different initial densities of hydrogen, deuterium and noble gases together with data for isentropic one. These calculations were carried out with codes implemented the improved SAHA-family models.

The calculations of principal Hugoniots of hydrogen and noble gases, the same for solid, liquid and pre-compressed gas targets in wide range of thermodynamic parameters together with isentropes are presented. The calculations have shown that in the considered pressure range dynamically compressed gas is in state of strongly coupled, degenerated plasma with density close to condensed matter. The obtained parameters of plasma are discussed together with those obtained in frames of first principal quantum methods. Results of these calculations are compared with all experimental data on shock and quasi-isentropically compressed hydrogen and noble gases.

T24: Tuesday 01.09.2015,16:30 - 16:50

Structural and thermodynamic properties of a nonideal two-temperature dense plasma

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In this work dense, nonideal, non-isothermal plasma was considered. New effective screened interaction potentials taking into account quantum-mechanical diffraction and symmetry effects were used [1]. The effective potential of the ion-ion interaction in plasmas with a strongly coupled ion subsystem and semiclassical electron subsystem is presented [1, 2]. These effective potentials can be used for nonisothermal and isothermal plasmas [3].

Based on the obtained effective potentials the analytical expressions for internal energy and the equation of state for fully ionized plasma were derived. The term $\sim e^2$ in the internal energy and in the equation of state disappears when $\lambda_{ee} \rightarrow 0$, $\lambda_{ei} \rightarrow 0$ in agreement with the recent work [4]. It is found that due to the symmetry effect the additional term $\sim n_e k_B T\ (n_e \lambda^3_{ee})$ in the inner energy of plasma and in the equation of state appears.

A comparison to the asymptotic theory and computer simulations suggests that the effective potentials, obtained in this paper, can be used to adequately describe the thermodynamic properties of the two-temperature dense plasma.

References

[1] T. S. Ramazanov, Zh. A. Moldabekov, and M. T. Gabdullin *Physical Review E*, 2015, 92, 023104.
[2] T. S. Ramazanov, K. N. Dzhumagulova, and M. T. Gabdullin *Phys. Plasmas*, 2010, 17, 042703.
[3] R. Bredow, Th. Bornath, and W.-D. Kraeft *Contrib. Plasma Phys.*, 2013, 53, 276.
[4] W. D. Kraeft, D. Kremp, and G. Reopke *Phys. Rev. E,* 2015, 91, 013108.

T25: Tuesday 01.09.2015,16:50 - 17:10

Features of Phase Transitions in the Models of Complex Plasma

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Some peculiarities of melting curves and crystal-crystal transitions in complex (i.e. dusty, colloidal and condensed dispersed phase (CDP)) plasmas are under discussion. Two simplified variants of complex plasmas models are considered as a thermodynamically equilibrium ensemble of classical Coulomb particles: a 2-component electroneutral system of macro- and microions (+Z, -1) and a 3-component electroneutral mixture of macro-ions and two kinds of microions (+Z, -1, +1). The base for a consideration is the well-known “Hamaguchi’s” phase diagram of dusty plasma [1] for an equilibrium charged system with the Yukawa potential in its standard representation in the coordinates: Γ-κ (Γ is the Coulomb non-ideality parameter, κ is the dimensionless Debye screening parameter). The phase regions for the three states of the system (fluid *vs*. bcc and fcc crystals) from the Hamaguchi diagram are reconstructed in the density-temperature coordinates. The resulting phase diagram in the logarithmic coordinates $\ln n$ - $\ln T$ has the form of a linear combination of crystalline and fluid zones separated by the boundaries $\Gamma = \text{const}$. Parameters and locations of these zones are analyzed in dependence on the intrinsic parameter of the model - macroion charge number *Z*. Parameters of a splitting the one-dimensional melting curve of the Hamaguchi diagram (i.e. hypothetical melting density gap between two separate boundaries freezing liquid line (*liquidus*) and melting crystal line (*solidus*)) are discussed. Estimation of a density gap based on an analogy of melting in Yukawa system with melting in the model of repulsive Soft Spheres (or IPL-model) was made [2,3]. Additional splitting of density for all phase boundaries in the three-component model of complex plasma (+Z, -1, +1) due to non-congruent nature [4] of all phase transitions in this model is also discussed. Close connection of the parameters for this non-congruence with another feature of phase interfaces in Coulomb systems, average electrostatic potential drop at the interface, was determined and discussed.

This work was supported by Russian Scientific Fund, Grant No: 14-50-00124.

References

[1] S. Hamaguchi, R. Farouki, D. Dubin, *Phys. Rev.* 1997, E 56, pp 4671–4682.
[2] I. Martynova, I. Iosilevskiy, Non-congruence, density gap and a phase diagram of dusty plasmas, *Zababakhin Scientific Readings* 2014. Snezhinsk: RFNC-VNIITF Publisher, 2014. p 168.
[3] I. Martynova, I. Iosilevskiy, On Melting Density Gap and Non-congruence of Phase Transitions in Models of Dusty and Colloid Plasmas. *Journal of Physics: Conference Series,* (to be published, 2015).
[4] I. Iosilevskiy, *Acta Phys. Polon. B (Proc. Suppl.),* 2010, **3**, p. 589// arXiv:1005.4186

15th International Conference on the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

Abstracts of posters: Session I

Tuesday 01.09.2015, 17:10 – 19:10

- statistical physics and ab-initio simulations
- equilibrium properties, equations of state and phase transitions – Part 1
- dense astrophysical and ICF plasmas
- dusty plasmas – Part 1

Nr.	Name	Surname	Title of Contribution
P1.1	Sebastien	Hamel	First-principles calculations of the high-pressure melting line of SiO2 and strenght of H2O: planetary science implications
P1.2	Ayatola	Gabdulin	MD Simulation of 2D System of Polarized Dust Particles
P1.3	Anatoly	Kupchishin	Cascade-Probability Method and Relationship with Markov Chains
P1.4	Alexandr	Larkin	Numerical Calculation of Thermodynamical Calculation of Thermodynamical Properties of Relativistic Particle in Potential Field
P1.5	Yaroslav	Lavrinenko	Boundary condition problem for atomistic simulations of classical and quantum strongly coupled systems of charged particles
P1.6	Péter	Magyar	Quadratic static response of the classical One-Component Plasma
P1.7	Alexey	Andreyev	Foundation of thermodynamics within the laws of the classical mechanics
P1.8	Yuriy	Arkhipov	Effective potentials in semiclassical two-component plasmas
P1.9	Asel	Ashikbayeva	Dynamic properties of Dirac plasmas in the random-phase approximation
P1.10	Alexander	Chigvintsev	Anomalous Phase Diagram in Simplest Plasma Model
P1.11	Yultuz	Omarbakiyeva	Cluster virial expansion of the equation of state for hydrogen plasma with e – H_2 contributions
P1.12	Jean-Christophe	Pain	Multi-configuration modeling of ionization potential depression in dense plasmas
P1.13	Aleksey	Shumikhin	The distinguishing features of the vapor-liquid (dielectric-metal) phase transition in metal vapors, semiconductors and rare gases
P1.14	Moldir	Issanova	Transport properties of inertial confinement fusion dense plasmas
P1.15	Nadine	Nettelmann	Warm Dense Hydrogen and Helium in Jupiter and Saturn: exploration of He sedimentation
P1.16	Nuriya	Bastykova	Controlled levitation of dust particles in rf+dc gas discharges
P1.17	Didar	Batryshev	Extraction of nano- and small dispersed microparticles in the plasma of radio-frequency discharge
P1.18	Lidia	Deputatova	Measurement of the charge of a single particle confined by the electrodynamic trap
P1.19	Merlan	Dosbolayev	The influence of the ionic composition of the plasma on dust structures in the combined discharge of radiofrequency and electrostatic fields
P1.20	Young-Dae	Jung	Nonthermal and geometric effects on the dual-mode surface waves in a Lorentzian dusty plasma slab
P1.21	Irina	Filatova	Plasma-assisted Functionalization of ZnO Nanoparticles and Production of Nanocrystalline ZnO Structures
P1.22	Alexey	Khrapak	Complex plasma research under microgravity conditions: PK-3 Plus laboratory on the International Space Station
P1.23	Ranna	Masheyeva	Effect of buffer gas induced friction on the cage correlation function of dust particles
P1.24	Vladimir	Messerle	Plasma for Fuel Processing
P1.25	Mukhit	Muratov	Influence of dipole interaction on the thermodynamic properties of dusty plasma

P1.1

First-principles calculations of the high-pressure melting line of SiO2 and strenght of H2O: planetary science implications.

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We report the results from high-pressure high-temperature quantum molecular dynamics simulations of two materials of importance to planetary science. First, we present the high-pressure melt line of SiO2 using constrained free energy calculations under conditions relevant to the Outer Planets and Super-Earths. Second, we explore the stability of the H2O super-ionic phase by calculating the elastic constants at finite temperature and provide insight into the generation of magnetic fields of Uranus and Neptune.

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P1.2

MD Simulation of 2D System of Polarized Dust Particles

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This work presents the results of molecular dynamics simulation of a 2D charged dust system taking into account the effect of induced dipole moment of a dust particle. As it is known, in gas discharge the dust particle and ions focused by the dust grain can be considered as one compound particle with non-zero dipole moment [1,2]. Such a picture is especially suitable for the description for a 2D dust system as there is no dust grain above the given dust particle, which can strongly effect focused ions. Non-symmetric dust particles can also have an induced dipole moment due to charge separation in the external electric field.

The interaction between particles located in the same horizontal layer was taken in the following form [4]:

$$\Phi = \frac{Q^2}{R}\exp(-Rk_S) + \frac{d^2}{R^3}(1+Rk_S)\exp(-Rk_S) \quad (1)$$

here k_s is the screening parameter, Q is the dust particle charge, and d is the dipole moment of the dust particle or of the given compound particle. As it is seen the interaction potential (1) gives a stronger repulsion between dust particles than the Yukawa potential.

Using the interaction potential (1) the structural properties and waves in the 2D dust system were studied. It was found that the maximum of the pair correlation function is higher than that of the Yukawa system.

References

[1] T.S. Ramazanov et al., Phys. Plasmas 18, 103705 (2011)
[2] G. I. Sukhinin and A. V. Fedoseev, Phys. Rev. E 81, 016402 (2010).
[3] T. S. Ramaznov, Zh. A. Moldabekov, M. T. Gabdullin, submitted for publication (2015).

P1.3

CASCADE-PROBABILITY METHOD AND RELATIONSHIPWITH MARKOV CHAINS

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We propose a cascade-probabilistic method. The work was performed within in the context of cascade-probabilistic method, the essence of which is to obtainand further application of cascade-probability functions (CPF) for different particles. CPF make senseprobability of that a particle generated at some depth h' reaches a certain depth h after the n-th number of collisions. We consider the interaction of ions with solids and relationship between radiation defect formationprocesses and Markov processes and Markov chains. It shows how to get the recurrence relations for thesimplest CPF from the Chapman-Kolmogorov equations. In this case the particle does not change its directionof movement after the collision, the flow rate does not depend on time, and consequently, on the depth ofpenetration. We also obtained recurrence relations for the CPF with the energy loss of ions from the Kolmogorov-Chapman equations, the flow rate depends on the depth of penetration.

P1.4

NUMERICAL CALCULATION OF THERMODYNAMICAL PROPERTIES OF RELATIVISTIC PARTICLE IN POTENTIAL FIELD

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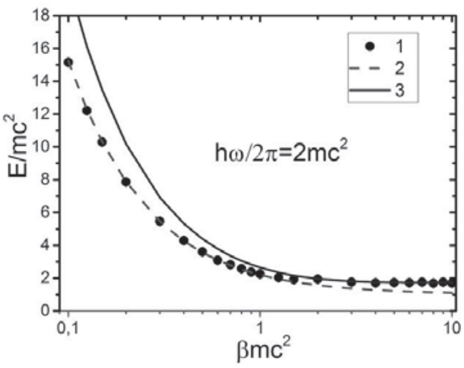
This work is devoted to first-principle calculations of thermodynamical properties of the relativistic particle in Newton-Wigner formalism [1]. Spinless Newton-Wigner particle in external potential field corresponds to positive-frequency solutions of relativistic wave equation called Klein-Gordon equation [2]:

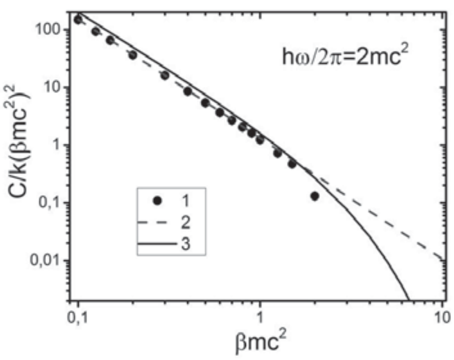
$$\left[\left(i\hbar\frac{\partial}{\partial t}-eA_0\right)^2-\left(-i\hbar\nabla-\frac{e}{c}\vec{A}\right)^2-m^2c^4\right]\phi(\vec{x},t)=0\,, \quad (1)$$

where A_0 is scalar potential, and (A_x, A_y, A_z) is vector potential of the field. This work was carried out generalization of the formalism of Wiener path integrals for the thermodynamic quantities [3] on relativistic Newton-Wigner particles and was developed quantum Monte-Carlo method to calculate them. To test the method, we calculated the average energy and heat capacity of a scalar particle Newton-Wigner in the harmonic potential in one-dimensional space. This system - relativistic harmonic oscillator - is described by the Hamiltonian:

$$\hat{H}=\sqrt{\hat{p}^2c^2+m^2c^4}+\frac{m\omega^2\hat{x}^2}{2}\,, \quad (2)$$

where m is mass of te particle, ω is a parameter of oscillator (circular frequency in non-relativistic case). Calculated dependence of average energy and heat capacity on the reciprocal temperature are shown on the left and right pictures respectively.





The points correspond to the results of numerical Monte-Carlo simulation, dashed lines – to the predictions of classical relativistic mechanics, and solid lines – to the predictions based on the approximate solution of the Klein-Gordon equation (valid for low temperatures). Good agreement between numerical calculations with the available information from the theory is achieved.

Литература:

[1]. Newton T.D., Wigner E.P. Localized states for elementary systems. Reviews of Modern Physics, 1949, vol.21, no.3. p.400-406.

[2]. Schweber S. An introduction to relativistic quantum field theory. Moscow, 1963.

[3]. Wiener N. Differential space. J. Math. and Phys., 1923, 2 , p. 132–174

P1.5

Boundary condition problem for atomistic simulations of classical and quantum strongly coupled systems of charged particles

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Theoretical studies of strongly coupled systems of charged particles such as electron-ion nonideal plasmas, ion liquids, dusty plasmas, etc. often rely on atomistic simulations by the methods of classical Molecular Dynamic (MD) and Monte-Carlo (MC) [1-4]. For both methods there is a long standing boundary condition problem when modelling an infinite spatially uniform system of particles interacting via the long-ranged Coulomb forces. This problem has an elegant solution for crystal-like systems called the Ewald summation, but it fails for disordered plasma or liquid as it may introduce artifacts due to unphysical periodicity. A typical choice for the disordered systems is the nearest image method, although some authors prefer reflecting walls [5].

The boundary problem becomes even more difficult for the so called Wave Packet Molecular Dynamics (WPMD) [6] where a single electron wave functions is represented by Gaussian wave packets with variable widths. Application of this method to rather dilute nondegenerate extended systems leads to the known problem of unrestricted wave packet spreading [7]. Although this spreading is a natural effect for the Gaussian wave function in an unrestricted space, the model of an extended system should also provide correct limitations on the density of allowed quantum states, which remains arbitrary when the wave packets are allowed to spread. Reflective boundary conditions for simulation box, which we investigate in this work, may be used as a direct method to provide the finiteness of the partition function.

In this work we start with a classical MD and perform a comprehensive study of convergence of thermodynamic quantities with the simulation box size growth for different types of boundary conditions. As simulations of large systems require large computing power we use a GPU-accelerated code. For the model of extended matter the effect of any boundary conditions should vanish as the system size grows. We study the limiting behaviour of various computed quantities and determine the number of particles for which the system size effect is negligible. A special attention is paid to the boundary conditions with soft (harmonic) reflecting walls, since they may be applied both for the WPMD and classical simulations. We compare the thermodynamics and system size effects for the classical and quantum models subjected to this type of boundary conditions.

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References

[1] J. P. Hansen and I. R. McDonald *Phys. Rev.* 1981 A 23 2041–59
[2] T. Pschiwul and G. Zwicknagel *J. Phys. A: Math. Gen.* 2003 36 6251–8
[3] I. V. Morozov and G. E. Norman *J. Exp. Theor. Phys.* 2005 100 370–84;
[4] L.X. Benedict, J.N. Glosli, D.F. Richards, et al. *Phys. Rev. Lett.*, 2009, 102, p 205004.
[5] S. A. Mayorov, A.N. Tkachev, S. I. Yakovlenko. *Physics-Uspekhi* 1994, 37.3, 279-288.
[6] D. Klakow, C. Toepffer, P.-G. Reinhard, *J. Chem. Phys.* 1994, 101, 10766.
[7] I. V. Morozov, and I. A. Valuev. *J. Phys. A: Math.,* 2009, 42.21, 214044.

P1.6

Quadratic static response of the classical One-Component Plasma

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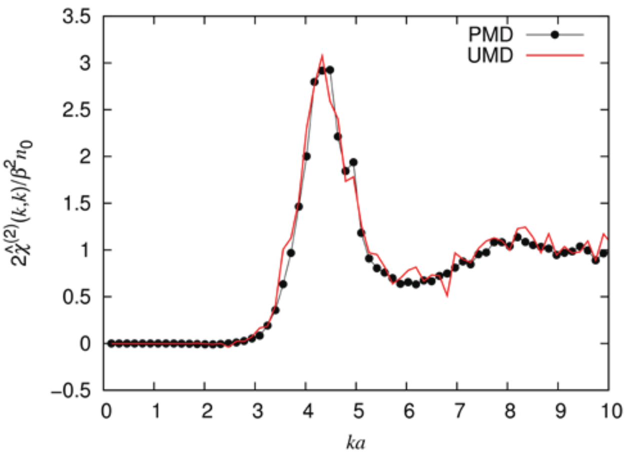
We investigate the static linear and quadratic density response functions and the related two-point (linear), $S^{(2)}$, and three-point (quadratic), $S^{(3)}$, static structure functions of equilibrium density fluctuations of the strongly coupled one-component plasma (OCP), via Molecular Dynamics (MD) simulations. To find the response functions we apply an external potential energy perturbation [1] and obtain the amplitudes of the responding density perturbations of different orders via Fourier analysis of the spatial density profile of the system ("perturbed MD" (PMD) simulations). To obtain the structure functions we use "unperturbed MD" (UMD) thermal equilibrium simulations. The structure functions are expected to be linked to the density response functions via the linear and quadratic fluctuation-dissipation theorems (FDT-s) [2-4]:

$$\hat{\chi}^{(1)}(\mathbf{k}_1) = -\beta\, n_0 S^{(2)}(\mathbf{k}_1) \quad , \quad \hat{\chi}^{(2)}(\mathbf{k}_1,\mathbf{k}_2;\mathbf{k}_0) = \frac{\beta^2 n_0}{2} S^{(3)}(\mathbf{k}_1,\mathbf{k}_2;\mathbf{k}_0),$$

where $\beta = 1 / kT$, and $\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_0 = 0$.



The figure shows the normalized quadratic density response function and the equilibrium quadratic static structure function $S^{(3)}(k,k)$, (i.e. $\mathbf{k}_1=\mathbf{k}_2$), for the coupling value of $\Gamma=50$ obtained from the two independent simulations. We find a good agreement between the two sets of data, providing the first computational verification of the quadratic FDT. (The wave number is in normalized units, *a* is the Wigner-Seitz radius.)

References

[1] P. Magyar, Z. Donkó, G. J. Kalman, K. I. Golden, *Phys. Rev. E*, 2014, **90**, 023102.
[2] K. I. Golden, G. J. Kalman, M. B. Silevitch, *J. Stat. Phys.*, 1972, **6**, 87.
[3] A. G. Sitenko, *Sov. Phys. JETP*, 1978, **48**, 51.
[4] K. I. Golden, J. T. Heath, *Contrib. Plasma Phys*. 2014, **55**, 236.

P1.7

Foundation of thermodynamics within the laws of the classical mechanics

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Methods for the numerical simulation of the dynamics equations of classical mechanics were used to determine the basic characteristics of the motion of an equilibrium system potentially interacting material points in an inhomogeneous field of forces. Also were defined the criteria that characterize the transition from a discrete description to the thermodynamic description of the system. Were explored changes in the internal energy of the system during the passage thrue the potential barrier depending on the width of the barrier, number of elements of the system, the initial conditions. Shown the variation of amplitude of energy parameters of the system depending on the number of material points. Carrying out the assessments of the dynamic entropy. Established two critical numbers. The first number determines the required number of matirial points for the transition to irreversible dynamics, and the second number specifies the transition to the thermodynamic description. Analyzed the results of matching the theoretical foundations of system dynamics.

Keywords: nonlinearity, classical mechanics, energy, thermodynamics, Lagrange formalism, nonholonomic constraints, irreversibility.

P1.8

Effective potentials in semiclassical two-component plasmas

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It is very well known that the application of the Coulomb potential to charged particle interactions in plasmas result in notorious problems caused by the divergence of the corresponding collision integrals both at small and large scattering angles. In order to amend this situation two types of pseudo potentials, called effective, were introduced to take into account quantum effects at short interparticle distances and the collective events at large separations.

The present work is aimed at constructing an effective potential, which simultaneously treats both the quantum diffraction and screening effects, and, at the same time, cares for quantum statistical phenomena at rather large particle number densities. This screened potential $\Phi_{ab}(\mathbf{r})$ is written in the framework of the linear density response theory as follows:

$$\Phi_{ab}(\mathbf{r}) = \frac{1}{(2\pi)^3}\int \mathbf{dk}\,\varphi_{ab}(k)\varepsilon^{-1}(k,0)\exp(i\mathbf{kr}), \qquad (1)$$

where $\varepsilon(k,0)$ stands for the static dielectric function (SDF) of the plasma, $\varphi_{ab}(k)$ denotes the Fourier transform of the effective potential chosen herein in the form of the so-called Deutsch potential mimicking the quantum diffraction effects. To take into account the screening effects, the SDF is taken in the following simple form [1]:

$$\varepsilon(k,0) = 1 + \frac{1}{(k/k_D)^2 + (k/k_q)^4}\ , \qquad (2)$$

where $k_D^2 = 4e^2\beta n_{tot}$, $n_{tot} = n_e + \sum_i n_i Z_i^2$, $k_q^4 = 16/\pi e^2/\mathrm{h}^2(n_e m_e + \sum_i n_i m_i Z_i^2)$ and h is the Planck constant.

The derived pseudopotential model is used for calculation of the equation of state and correlation energy to find a good agreement with the results of [2] at rather high temperatures.

References

[1] V.M. Adamyan, I.M. Tkachenko. *Teplofizika Vysokikh Temperatur*, 1983, 21, pp 417-425.
[2] J. Vorberger and D.O. Gericke. Aug 25 2011, physics.plasm-ph arXiv:1108.4826v1.

P1.9

Dynamic properties of Dirac plasmas in the random-phase approximation

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There is a number of examples presenting the model of a Dirac massless fermion plasma. They correspond to different systems with the relativistic energy of a single particle with the rest mass m and momentum ħp=ħ|**p**|: $E_{\boldsymbol{p}} = \sqrt{(m\,c^2)^2 + (\hbar p v)^2}$, where the rest contribution is negligible so that $E_{\boldsymbol{p}}$ can be approximated as $E_{\boldsymbol{p}} = \hbar p v$, $\hbar$ is, of course, the Planck constant. The most frequently encountered examples are the two-dimensional system of Dirac fermions in graphene which mimics relativistic particles with zero rest mass and have an effective "speed of light" $c^* < 10^6$ ms^{-1}: $E_p^g = \hbar p c^*$ [1], see also [2], and the three-dimensional ultrarelativistic plasma with $E_p^{ur} = \hbar p c$ [3] also studied in the context of quark-gluon plasmas [4]. Note that in a Dirac (one-component) plasma of a non-zero temperature β^{-1}, along the Wigner-Seitz and Debye radii, the Landau, and Fermi, length there exists a specific characteristic length, $\ell = \beta\hbar v$. Another characteristic feature of systems of Dirac charged fermions is the presence of an explicitly non-classical (in all dimensions) optical long-wavelength collective mode with the "plasma frequency" being proportional to $\hbar^{-1/2}$ [5]. The collective properties of two-dimensional Dirac fermions were studied in [6] in the random-phase and quasi-localized charge approximations. In the present work we construct the (longitudinal) dielectric function and study the collective mode in three-, two-, and one-dimensional Dirac plasmas in the random-phase approximation (RPA). Further studies of massless Dirac plasmas, including electron-positron and quark-gluon systems and electrons in graphene, including on the basis of the approach based on the classical method of moments [7] are planned.

References

[1] K.S. Novoselov et al., *Nature*, 2005. 438, 197.
[2] A.H. Castro Neto et al., *Rev. Mod. Phys.*,2009, 81, 109.
[3] R. Shaisultanov, Yu. Lyubarsky, and D. Eichler, *Astrophys. J.*, 2012, 744, 182.
[4] U. Heinz, J. Phys. A, 2009, 42, 214003; M.H. Thoma, *J. Phys. A*, 2009. 42, 214004.
[5] S. Das Sarma and E.H. Hwang, *Phys. Rev. Lett.*, 2009, 102, 206412.
[6] P. Hartmann, G.J. Kalman, K.I. Golden, Z. Donko, *J. Phys. A*, 42, 214018.
[7] M.G. Krein and A.A. Nudel'man, *The Markov moment problem and extremal problems*, Trans. of Math. Monographs, Vol. 50 (Amer. Math. Soc., Providence, R.I., 1977); V.M. Adamyan, I.M. Tkachenko, Contrib. Plasma Phys., 2003, 43, 252; Yu.V. Arkhipov et al., Phys. Rev. E, 2007, 026403; I.M. Tkachenko, Yu.V. Arkhipov, A. Askaruly, *The Method of Moments and its Applications in Plasma Physics*, Saarbrücken: LAMBERT, 2012; Yu.V. Arkhipov et al., Phys. Rev. E, 81, 026402 (2010).

P1.10

ANOMALOUS PHASE DIAGRAM IN SIMPLEST PLASMA MODEL

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The variety of simplest plasma models with a common feature - absence of correlation of charges of opposite sign - is studied. (OCP of ions on the background of ideal fermi-gas of electrons; a superposition of two OCP models of ions and electrons *etc*.) In all the models the background is considered as uniform and *compressible* media. It results in: (i) variation of crystal and liquid densities at melting [1]; and (ii) appearance of a new gas-liquid phase transition [2,3] with properties strongly depending on the value of ionic charge number z.

An anomalous phase diagram is realized in the model at sufficiently high value of ionic charge ($z^*_1 \le z \le z^*_2$). The only one unified crystal-fluid phase transition exists as continuos superposition of melting and sublimation. The pseudo-critical point exists in both cases $z = z^*_1$ and $z = z^*_2$. The critical isotherm is cubic in this case. Any critical point is absent at intermediate values of charge number z ($z^*_1 < z < z^*_2$). A complicated structure of spinodals accompanied the phase diagram discussed. The real calculations have been made for OCP of classical ions on the ideal electron gas background. In this case $z^*_1 \approx 35.5$ and $z^*_2 \approx 40.0$.

The discussed phase transition may be reproduced, in principle, by means of direct numerical simulation.

References

1. Pollock E.L., Hansen J.P. *Phys.Rev.* **A 8**, 3110,(1973).
2. Iosilevski I.L. and. Chigvintsev A.Yu, «*Physics of Nonideal Plasmas*», /ed. by W.Ebeling, A.Foerster and R.Radtke/, Teubner-Texte zur Physik. B 26, Stuttgart-Leipzig, 1992, p.87.
3. Iosilevski I.L. and. Chigvintsev A.Yu, «*Physics of Strongly Coupled Plasmas*», /ed. by W.D. Kraeft and M. Schlanges/, World Scientific, 1996, p. 145.

P1.11

Cluster virial expansion of the equation of state for hydrogen plasma with e – H_2 contributions

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The equation of state of partially ionized hydrogen plasma is considered with special focus on the contribution of e – H_2 interaction. Traditional semi empirical concepts such as the excluded volume are improved using microscopic approaches to treat the e – H_2 problem. Within a cluster virial expansion, the Beth-Uhlenbeck formula is applied to infer the contribution of bound and scattering states to the temperature dependent second virial coefficient. The scattering states are calculated using the phase expansion method for the polarization interaction that incorporates experimental data for the e – H_2 scattering cross section. We present results for the scattering phase shifts, differential scattering cross sections, and the second virial coefficient due to e – H_2 interaction. The influence of this interaction on the composition of the partially ionized hydrogen plasma is confined to the parameter range where both the e – H_2 and the free electron components are abundant [1].

References

[1] Y. A. Omarbakiyeva, H. Reinholz, G. Röpke *Phys. Rev. E*, 2015, accepted.

P1.12

Multi-Configuration Modeling of Ionization Potential Depression in Dense Plasmas

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The modeling of plasmas at high density and temperature is crucial for research related to astrophysics and inertial confinement fusion. Understanding how the environment of ions is modified when the density increases around solid density is important for equation-of-state and radiative-opacity calculations. The ionization potential depression (IPD) was recently measured for aluminum using the LCLS X-ray free-electron laser [1], used to ionize the K shell at solid density. The fact that ionization occurs or not depends on laser energy and the diagnostics were performed by K_α emission. The IPD measured for different charge states were better reproduced by the Ecker-Kröll model [2] than by the Stewart-Pyatt model [3], which predicts a too small depression. Another recent experiment involved a combination of short and long pulse beams at the new laser facility ORION [4]. The spectroscopic measurements were performed on shocked aluminum and the presence or absence of $n=3 \rightarrow n=1$ lines according to different values of temperature and density was used to infer IPD. The results were in good agreement with the Stewart-Pyatt predictions. In order to decide between those two analytical models, one needs to resort to quantum-mechanical atomic-structure calculations. Usually, the investigations rely on the average-atom model, but such a scheme is unable to provide different IPD for different charge states [5]. It is important to correctly take into account the number of bound electrons (and not merely an average) to obtain realistic free-electron density profiles (and hence IPD) around each ion. In the present work, in contrast with average-atom models, a self-consistent scheme is solved independently for each electronic configuration. Free electron densities are computed quantum mechanically including resonances [6,7].

References

[1] O. Ciricosta et al., *Phys. Rev. Lett.*, 2012, **109**, 065002.
[2] G. Ecker and W. Kröll, *Phys. Fluids*, 1963, **6**, pp. 62-69.
[3] J.C. Stewart and K.D. Pyatt, *Astrophys. J.*, 1966, **144**, pp. 1203-1211.
[4] D.J. Hoarty et al, Phys. Rev. Lett., 2013, **110**, 265003.
[5] G. Massacrier, A.Y. Potekhin and G. Chabrier, *Phys. Rev. E*, 2011, **84**, 056406.
[6] J.-C. Pain, G. Dejonghe and T. Blenski, *JQSRT*, 2006, **99**, pp. 451-468.
[7] J.-C. Pain, G. Dejonghe and T. Blenski, *Contrib. Plasma Phys.*, 2012, **52**, pp. 23-27.

P1.13

The distinguishing features of the vapor-liquid (dielectric-metal) phase transition in metal vapors, semiconductors and rare gases

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The unified thermodynamic model that allows to calculate the parameters of the critical point and binodal for insulator-metal (vapor-liquid) phase transition in the vapors of various metals and semiconductors, atomic hydrogen and rare gases is suggested. The model is based on the assumption that the transition is appeared in a dense atomic gas (gas near the critical point) due to special kind of attraction between the atoms caused by the appearance of the conduction electrons and the conduction band. For liquid and solid metallic states this attraction is well known – it is a cohesion (cohesive energy). For atomic hydrogen [1], alkali metal vapors [2] and the gas of excitons [3] cohesion can be calculated analytically for all atom densities. For other metals having many-electron valence shell, cohesion can be calculated only numerically using the Hartree-Fock method and the density functional theory. We used the scaling dependences for energy coupling, generalizing the results of numerous numerical computations for such metals. These dependences are described by a simple and universal expression for various types of binding energy [4] (Universal Bind Energy Relation, UBER). Universal expression for the cohesive energy is defined through evaporation energy, normal density and isothermal elastic modulus of the substance at normal density.

When the temperature decreases isotherms for all substances, considered as in [1, 2], show the appearance of the van der Waals loops, which clearly indicates the presence of the first order vapor-liquid phase transition. Analyzing the isotherms we can immediately estimate the critical temperature, density and pressure. Calculations are performed for transition metals and semiconductors also. We applied our model to the calculation of the critical parameters of the vapor-liquid phase transition in rare gases.

The calculated critical point parameters were in reasonable good agreement with the experimental data for the alkali metals and with estimates of the critical point parameters of various metals made by other authors. The model allows to calculate analytically the vapor-liquid phase transition binodal for all considered substances and to obtain the density of the liquid and the gas phases near the critical point. The liquid phase is a metallic one (except rare gases) because it contains conduction electrons.

Thus, in this paper we propose a new method for calculating the parameters of the critical points and binodal of the vapor-liquid (insulator-metal) phase transition in the vapors of various metals, semiconductors, atomic hydrogen and rare gases. All transitions are of the same nature, as described by an unified thermodynamic model, which is based on a single hypothesis about the dominant role of quantum collective interatomic bonding energy - cohesion for condensed matter, and in the gas near the critical point.

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References

[1] A.L. Khomkin, A.S. Shumikhin *Plasma Physics Rep.*, 2013, **39** (10), p. 958.
[2] A.L. Khomkin, A.S. Shumikhin *JETP*, 2014, **145**, p. 84.
[3] A.L. Khomkin, A.S. Shumikhin *JETP*, 2015, **147**, p. 775.
[4] J.R. Smith, J.H. Rose, F. Guinea, J. Ferrante *Phys. Rev B*, 1984, **29**, p. 2963.

P1.14

Transport properties of inertial confinement fusion dense plasmas

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Studying of transport properties of the dense plasma is a great importance for plasma physics, as well as for the problems of inertial confinement fusion (ICF), warm dense matter driven by heavy ion beams [1]. Calculation of parameters of inertial fusion drivers $n_e > 10^{22}\,см^{-3}$ of heavy ion beams requires adequate quantitative description of the interaction of heavy ion beams with dense plasma in a wide range of parameters. Consequently, knowledge of transport properties in the plasma will enable us to calculate the design of thermonuclear target more accurately. These properties of plasma can be calculated accurately taking into account both quantum and collective effects in plasmas. One of the important values describing the transport coefficients of deuterium-tritium plasma is the Coulomb logarithm [2]. The Coulomb logarithm is obtained on the basis of effective potentials. These interaction potentials take into consideration long-range many particle screening effects as well as short-range quantum-mechanical effects [3]. For inertial confinement fusion applications, we have calculated deuterium thermal conductivity and electrical conductivity in a wide range of densities and temperatures. The results obtained for thermal conductivity and electrical conductivity are compared with the available experimental data [4] and the results of quantum molecular-dynamics simulation [5].

References

[1] V.E. Fortov. Extreme states of matter on Earth and in the Cosmos. – *Springer*, 2009
[2] T.S. Ramazanov, S.K. Kodanova, Zh.A. Moldabekov, M.K.Issanova. *Phys. Plasmas*, 2013, 20, P. 112702.
[3] S.K. Kodanova, T.S. Ramazanov, M.K. Issanova, Zh.A. Moldabekov, G. Nigmetova. *Contrib. Plasma Phys.*, 2015, 55 (2-3), pp 271 – 276.
[4] J.R. Adams, N.S. Shilkin, V.E. Fortov, V.K. Gryaznov, V.B. Mintsev, R. Redmer, H. Reinholz, and G. Ropke. *Phys. Plasmas*, 2007, 14, P. 062303.
[5] S.X. Hu, L.A. Collins, T.R. Boehly, J.D. Kress, V.N. Goncharov and S. Skupsky. *Phys. Rev.*, 2014, E 89, P. 043105.

P1.15

Warm Dense Hydrogen and Helium in Jupiter and Saturn: exploration of He sedimentation

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Considerable resources have been mobilized to understand the behavior of H and He under high pressures and temperatures, and to detect and characterize giant planets in our own as well as in other solar systems. Both efforts are linked by two important discoveries: giant planets consist predominantly of H and He, although the amount and origin of additional constituents remains a matter of intense investigation [1]; second, high-precision input data based planet models such as available for Jupiter and Saturn can help understand the behavior of warm, dense hydrogen and helium [2-5].

Previous work has successfully aimed at explaining the measured planetary gravitational field and shape properties. In particular, our recently improved H-He EOS predicts a slightly higher maximum atmospheric metallicity for Jupiter, as well as larger radii for brown dwarfs compared to models based on earlier EOSs [3]. However, standard planet models appear incapable of explaining Jupiter's atmospheric depletion in helium and neon, or Saturn's high luminosity and dipolar magnetic field [2]. To explain those properties is the goal of the current work.

Here we apply H/He demixing diagram data and transport properties based on ab initio simulations, to study the interior of Jupiter and Saturn with helium sedimentation. This effect offers a solution to the outlined open questions.

For Jupiter, our models predict a shallow He rain zone between 1 and at few Mbar [4]. The measured atmospheric He abundance and luminosity can simultaneously be reproduced if He droplets are assumed to rain out instantaneously and if the He rain zone is superadiabatic [4]. For Saturn, our models suggest a thick He rain zone that may extend down to core, so that high-order magnetic field moments may be suppressed [5].

Our work clearly demonstrates the need for more combined efforts -on experimental, theoretical, and observational grounds- for understanding giant planets and the matter they are made of. We encourage probing the H/He phase diagram, measuring Saturn's He and Ne abundances, and to numerically study the formation and sinking of He droplets in a (semi-)convective environment.

References

[1] J.J. Fortney, N. Miller, *Astrophys. J. Lett.*, 2011 (726), L29
[2] N. Nettelmann, R. Püstow, R. Redmer, Icarus, 2013 (225), 548
[3] A. Becker, W. Lorenzen, R. Redmer et al., *Astrophys. J. Suppl.*, 2014 (215), 14
[4] N. Nettelmann, J.J. Fortney, K. Moore, C. Mankovich, *MNRAS*, 2015 (447), 3422
[5] R. Püstow, N. Nettelmann, W. Lorenzen, R. Redmer, *submitted*

P1.16

Controlled Levitation of Dust Particles in RF+DC Gas Discharges

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Following our earlier studies [1], here we investigate experimentally and via computer simulations, for a wide range of discharge conditions, the equilibrium levitation height of dust particles in plane-parallel electrode discharges, established by combined rf and dc excitation.

In our experiments two flat stainless steel electrodes with a diameter of D = 170 mm are placed horizontally, at an adjustable distance of L = 15…36 mm from each other, inside a glass cylinder. The lower electrode is powered via a coaxial feedthrough by an rf power supply operating at f_{RF} = 13.56 MHz and at peak-to-peak voltages between V_{pp} = 90 V and 150 V. The (argon) gas pressure ranges between p = 5.6 Pa and 40 Pa. A separate power supply, connected to the powered electrode via a rf choke makes it possible to introduce an *external* dc bias between -100V and +100V. (Due to the high degree of symmetry of the electrode configuration the dc *self bias* of the plasma is below 2 V.) Melamine-formaldehyde micro-particles with a radius of r_d = 2.19 μm are used to establish a dust layer, which is illuminated through a side window of the plasma chamber with a 440 nm wavelength laser. Light scattering images are taken with an Allied Vision ProSilica CCD camera.

The plasma is described by Particle-in-Cell simulation incorporating Monte Carlo treatment of collision processes (PIC/MCC). We assume that the number density of the dust is low, i.e. the presence of the dust has no influence on the discharge characteristics. This approach – although it breaks the complete self-consistency of the calculations – avoids the computational difficulties that arise because of the extremely different timescales of the motion of electrons, ions, and the dust particles [2]. The levitation height of the dust layer in the discharge is determined from the balance of the vertical forces acting on the particles: gravity, electrostatic, and ion drag forces. The computations of the floating potential and the electric charge of dust particles (which are needed for the calculation of the forces) proceeds as in [3]: the interaction (collisions) between electrons and ions with the dust particles are described by cross sections that correspond to the Orbital Motion Limited (OML) approximation. Our studies indicate that the external dc bias provides a solid control over the position of the dust layer within a wide range of discharge conditions.

References

[1] N. Kh. Bastykova, A. Zs. Kovács, S. K. Kodanova, T. S. Ramazanov, I. Korolov, P. Hartmann, Z. Donkó, in *Proceedings of 20th SAPP* (*Symposium of Application of Plasma Processes*), Slovakia, 17-22 January 2015, p. 286.
[2] K. Matyash, R. Schneider, H. Kersten 2005 *J. Phys.: Conf. Series* **11** 248; V. Land, L. S. Matthews, T. W. Hyde, D. Bolser 2010 *Phys. Rev. E* **81** 056402.
[3] A. L. Alexandrov, I. V. Schweigert , F. M. Peeters 2008 *New J. Phys.* **10** 093025; S. A. Khrapak, A. V. Ivlev 2010 in *Complex and Dusty Plasmas* (CRC Press).

P1.17

Extraction of nano- and small dispersed microparticles in the plasma of radio-frequency discharge

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Dusty plasma is an ionized gas containing nano- and micrometer sized particles of solid matter (dusts). Such solid particles in the plasma acquire a negative charge due to the high mobility of electron and levitate in it forming a plasma crystal. Investigation of plasma crystal is still ongoing in many research groups. In this work the method of extraction of nano- and microparticles in the plasma of radio-frequency discharge is considered. The proposed method is based on capture and control of the dusts using special traps that enable to modify the equipotential surface in the radio-frequency discharge plasma [1–3]. Using this method the fraction of silica nanoparticles with the average diameter of 600 nm was obtained and the fraction of small dispersed microparticles with the average diameter of 5 μm was also obtained. The polydispersive silica and alumina particles were used as initial powder for separation with size of particles in range of hundred nanometers up to hundreds micrometers. The advantages of the proposed method are the simplicity of technology and small dispersion of obtained particles after extraction as compared with existing analogues.

References

[1] D.G. Batryshev, T.S. Ramazanov, M.K. Dosbolayev, M.T. Gabdullin, Journal of nano- and electronic physics, 2014; Vol. 6 No 3, 03032(3pp).
[2] D. G. Batryshev, T. S. Ramazanov, M. K. Dosbolayev, and M. T. Gabdullin, Contrib. Plasma Phys., 1 – 6 (2015) / DOI 10.1002.
[3] D. G. Batryshev, T. S. Ramazanov, M. K. Dosbolayev, M. T. Gabdullin, S.A. Orazbayev, News NAS RK, 2014; No. 2, P. 145.

P1.18

Measurement of the charge of a single particle confined by the electrodynamic trap

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The electrodynamic traps enable to form structures of charged dust particles [1]. In this work measurements of charges and masses of single dust particles confined by the electrodynamic trap at atmospheric pressure were carried out. Particles got charge in a charger with the corona discharge. The charge of the particle was determined by its equilibration in the electric field. To determine the charge we need to find an electric field value and the particle mass. The mass of the particle was determined by its free fall velocity measurement. The electric filed was found using results of the simulation of the real electrodynamic trap. In the experiments polydisperse Al_2O_3 powder and calibrated spherical shape melamine formaldehyde particles with a diameter of 10 μm were used. The measured charge values of Al_2O_3 particles were equal to $2.5\cdot10^5$ e (17.6 μm), $3.5\cdot10^5$ e (22.6 μm) and $18\cdot10^5$ e (38.9 μm). The measured charge value of melamine formaldehyde particle was equal to $2.1\cdot10^5$ e (9.83 μm). The charge measurement method proposed in this work can be useful to evaluate an effectiveness of charger devices. This work has been done due to the financial support of the grant of the Russian Science foundation number 14-50-00124.

References

[1] Vasilyak L M, Vladimirov V I, Deputatova L V, Lapitsky D S, Molotkov V I, Pecherkin V Y, Filinov V S and Fortov V E 2013 *New Journal of Physics* **15** 043047.

P1.19

The influence of the ionic composition of the plasma on dust structures in the combined discharge of radiofrequency and electrostatic fields

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Gas discharge of combined radiofrequency and direct current is used in many plasma technologies, especially in cleaning and surface treatment of materials, in sterilization of medical instruments, etc. [1-4]. In this type of combined discharge the ions flow towards one of the electrodes can be controlled. It could be useful in dielectric barrier discharge, for example, in making of nano-coating on the dielectric substrate, where the directed ion flow plays a main role.

In this paper the results of the experimental investigation of the effect of ionic composition on the dust structures in the combined discharge are presented. The experiments were carried out on the RF setup, which detailed descriptions are shown in [5-7]. It was shown that the influence of the ion flow on the formation of the vertical chain structures demonstrate some several features. Also, the influence of the composition of the ion flow on the dusty structures was investigated. One can conclude that it is possible to control formation of dust structures by the ionic composition.

Also, the structural properties of plasma-dust structures were studied. It was shown that increasing constant field in the combined RF and DC discharge decreases the average interparticle distance.

References

[1] Lai W.T., Hwang C.J., Wang A.T., Yau J.C., Liao J.H., Chen L.H., Adachi K., Okamoto S. // Proceedings of the International Symposium on Dry Process. Japan: Nagoya, Institute of Electrical Engineers; 2006. - P.109.
[2] Kawamura E., Lieberman M.A., Lichtenberg A.J., Hudson E.A. // J. Vac. Sci. Technol. A. – 2007. - Vol. 25, υ5. – P. 1456-1474.
[3] Denpoh K., Ventzek P.L.G. // J. Vac. Sci. Technol. A. – 2008. – Vol. 26, υ6. - P. 1415-1424.
[4] V.A. Lysovskii, N.D. Harchenko // Vestnik Har'kovskogo universiteta, seria fizika "yadra, chastic, polya", (in Russian) № 899, v.2. 2010.
[5] Ramazanov T.S., Dzhumagulova K.N., Jumabekov A.N., Dosbolayev M.K. // Phys. Plasmas 15, 053704. – 2008
[6] M.K. Dosbolayev, A.U. Utegenov, T.S. Ramazanov, T.T. Daniyarov // Contrib. Plasma. Phys. 53, No. 4-5. – 2013. P. 426-431.
[7] T.S. Ramazanov, T.T. Daniyarov, S.A. Maiorov, S.K. Kodanova, M.K. Dosbolayev, E.B. Zhankarashev // Contrib. Plasma. Phys. 51, No. 6. – 2011. P. 505-508.

P1.20

Nonthermal and geometric effects on the dual-mode surface waves in a Lorentzian dusty plasma slab

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The nonthermal and geometric effects on the propagation of the surface dust acoustic waves are investigated in a Lorentzian dusty plasma slab. The symmetric and anti-symmetric dispersion modes of the dust acoustic waves are obtained by the plasma dielectric function with the spectral reflection conditions the slab geometry. The variation of the nonthermal and geometric effects on the symmetric and the anti-symmetric modes of the surface plasma waves is also discussed.

P1.21

Plasma-assisted Functionalization of ZnO Nanoparticles and Production of Nanocrystalline ZnO Structures

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Zinc oxide (ZnO), owing to its unique physical and chemical properties, variety of nanometric ZnO structures can be considered as a multifunctional material with potential large-scale technological applications. In the recent years many researchers carrying out numerous studies to find methods of production or modifying the surface of the ZnO compounds for their new possible applications.

In this work, the experiments on the production of nanocrystalline structures of zinc oxide by thermal method in high-frequency gas discharge were done and a method is proposed for ZnO powders modification using plasma treatment in order to improve their photocatalytic activity.

The synthesis process was carried out in the plasma of inert gas mixtures. At the heating of the evaporator the molecule of the produced zinc injected into the plasma volume and agglomerated the nanoparticles. In the plasma the negatively charged zinc nanoparticles (dusty plasma) are deposited on a silicon substrate, forming a parallel array of the oriented nanorods of ZnO.

Modification of ZnO powders was conducted the air plasma of capacitively coupled RF discharge at a pressure of 60 Pa. Particles were injected into the plasma by means of a piezoelectric radiator which was placed on the lower grounded electrode. Dust particles levitated above the lower electrode that provided a uniform treatment of the material. A method has been proposed for the evaluation of the kinetic of Methyl Orange (MO) photodegradation over ZnO. The experimental results proved that the plasma modified ZnO powders presented promising photocatalytic activity toward the dye photodegradation (fig. 1).

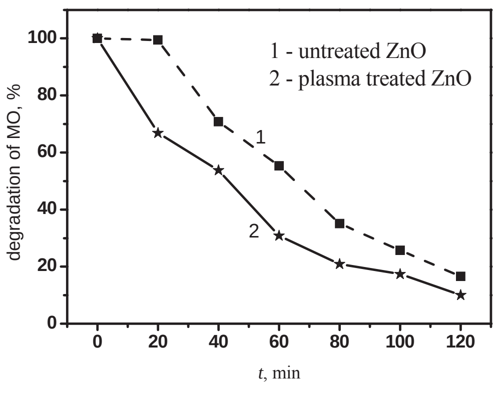

Fig. 1. Effect of ZnO nanoparticles on photocatalytic degradation of MO

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P1.22

Complex plasma research under microgravity conditions: PK-3 Plus laboratory on the International Space Station

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Complex (dusty) plasmas are composed of weakly ionised gas and charged microparticles and represent the plasma state of soft matter. Due to the “heavy” component – the microparticles – and the low density of the surrounding medium, the rarefied gas and plasma, it is necessary to perform experiments under microgravity conditions to cover a broad range of experimental parameters which are not available on ground. The investigations have been performed onboard the International Space Station (ISS) with the help of the “Plasma Crystal-3 Plus” (PK-3 Plus) laboratory. This laboratory was mainly built to investigate the crystalline state of complex plasma, the so-called plasma crystal, its phase transitions and processes in multi-particle mixtures. Some interesting phenomena will be observed. Due to the manipulation of the interaction potential between the microparticles it is possible to initiate a phase transition from isotropic plasma into electrorheological plasma. The crystal-liquid phase transition was obtained in large 3D isotropic dusty plasma system using a neutral gas pressure as a convenient control parameter to drive crystallization and melting. The compression of the dust particle subsystem can result in melting of the plasma crystals that is attributed to a drop of the absolute magnitude of the particle charge with their density increase.
Besides, we will discuss different research achievements of PK-3 Plus on the ISS.

The authors gratefully acknowledge the support from the Russian Science Foundation (Project No. 14-12-01235).

P1.23

Effect of buffer gas induced friction on the cage correlation function of dust particles

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Strongly coupled plasmas (SCP-s) are present in various forms in nature and laboratory settings, and represent a rapidly emerging field of research. Dusty plasmas represent a notable type of such systems, which appear both in astrophysical environments and can be realized in laboratory experiments. The physical properties of dusty plasmas are important for the development of the different areas of modern physics and new technology, for example, laser technology, fusion energy, astrophysics, physics of the upper atmosphere, nanotechnology, etc.

A prominent feature of strongly coupled plasmas is that the surrounding of the particles changes on a timescale that is long compared to the timescale of plasma oscillations. This "quasi-localization" [1] has a primary importance in establishing the properties of SCP-s, including transport and collective excitations. The quasi-localization of the particles can be quantified by cage correlation functions that account for the changes of particles' neighbor shells. Caging of the particles in 2- and 3-dimensional strongly coupled, ideal (frictionless) Yukawa liquids was investigated in [2]. As a further step, the effect of a homogenous external magnetic field on the cage correlation functions was investigated in [3]. The purpose of the present work is to study the effect of friction, induced by the buffer gas, on the cage correlation functions in a non-magnetized system of dust particles, which interact via screened Coulomb (Debye-Huckel, or Yukawa) potential. Computer simulations were carried out based on the Langevin dynamics approach [4], for the cage correlation function of the dust particles,

$$C_{cage}^{c}(t) = \left\langle \Theta(c - n_i^{out}) \right\rangle,$$

where Θ is the Heaviside function, Our studies cover a wide range of the system parameters (coupling strength Γ, screening parameter κ, and friction parameter θ). The results indicate that an increasing friction slows down the decay of the cage correlation function, which can be attributed to the fact that a strong friction hinders the diffusion of the particles, which, in this way, spend more time in the cages composed by the neighbors.

[1] K. I. Golden and G. J. Kalman, *Phys. Plasmas* **7** (2000) 14
[2] Z. Donkó, G. J. Kalman, and K. I. Golden, *Phys. Rev. Lett.* **88** (2002) 225001;
Z. Donkó, P. Hartmann, and G. J. Kalman, *Phys. Plasmas.* **10** (2003) 1563
[3] K.N. Dzhumagulova, R.U. Masheeva, T.S. Ramazanov and Z. Donkó, *Phys. Rev. E* **89** (2014) 033104
[4] K. N. Dzhumagulova, T. S. Ramazanov, Y.A. Ussenov, M.K. Dosbolayev and R. U. Masheeva, *Contrib. Plasma Phys.* **53** (2013) 419

P1.24

Plasma for Fuel Processing

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A review of the developed plasma technologies of pyrolysis, hydrogenation, thermochemical treatment for combustion, gasification, radiation-plasma, and complex conversion of solid fuels, including uranium-containing slate coal, cracking of hydrocarbon gases and biomedical waste processing, is presented. The use of these technologies for obtaining target products (hydrogen, carbon black, hydrocarbon gases, synthetic gas, and valuable components of the coal mineral mass) meet the modern experimental and economic requirements to the power sector, metallurgy, chemical, medical and pharmaceutical industry. Plasma solid fuel conversion technologies are characterized by a small time of reagents retention in the reactor and a high rate of the original substances conversion to the target products without catalysts. Parameters of the used arc plasma correspond to the characteristics of dusty plasma.

Plasma conversion for combustion of coal from the original low-grade coal produces a high-reactivity two-component fuel that actively ignites when mixed with secondary air in the boiler furnace and burns stably without combustion of additional high-reactivity fuel, fuel oil or gas, traditionally used for boiler firing and lighting of the dust-coal flame at thermal power plants. During complex coal conversion, the conversion of its mineral part requires high temperatures (2200–3100 K), increasing the specific power consumption to 2–4 kW h/kg. It gives a high degree of coal conversion (90-100%). Plasma-steam gasification ensures the transfer to the gaseous phase of the organic coal mass, basically, which does not require very high temperatures as during complex treatment, thus allowing the process with comparatively low specific power consumption rates (0.5–1.5 kW h/kg) and high conversion degrees (90–100%). Radiation-plasma coal conversion increases the original fuel conversion degree by 48%. Plasma treatment of uranium-containing slate coal reached the following indicators: at temperatures 2700–2900 K the slate coal gasification degree was 56.2–66.4%, the conversion of microelements to the gaseous phase reached 48.0–78.6% for uranium, 54.5–79.0% for molybdenum, and 58.6–81.3% for vanadium, which agreed with the TERRA calculations in terms of quality. Plasma hydrogenation of coal requires high temperatures (2800–3200 K), which results in high power consumption for this process (6.5–8 kW h/kg), thereby allowing high conversion degrees (70–100%) for direct (one stage) production of acetylene and alkenes in the gaseous phase. In order to ensure high conversion degrees (98–100%) of the hydrocarbon gas in a combined plasmachemical reactor, such high temperatures are not needed, which allows the process with relatively low specific power consumption (2.0–3.8 kW h/kg).

All the processes of the plasma processing of fuels and waste showed their environmental and energy efficiency, and therefore the prospects for industrial use.

P1.25

Influence of dipole interaction on the thermodynamic properties of dusty plasma

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This work is devoted to a theoretical consideration of the influence of dipole interaction between dust grains on the thermodynamic properties of plasma-dust systems. Equation of state (pressure) was derived in the framework of the investigation of the thermodynamics of dusty plasma. Pair correlation functions of dusty plasma's particles are calculated for system of particles interacting through the effective potential [1]. Effective interaction potential is for particles with dipole moment and takes into account screening effects at large distance. On the basis of the mentioned calucations investigation of the influence of dipole interaction on the thermodynamic properties is presented. Also, the comparisions of obtained results with data based on the experimental pair correlation functions, and also with previous theoretical and calculated results are presented [2-4].

References

[1] T.S. Ramazanov, Zh.A. Moldabekov, K.N. Dzhumagulova and M.M. Muratov, *Phys. Plasmas,* **18** (2011), P.103705.
[2] T.S. Ramazanov, K.N. Dzhumagulova et al., Contrib. Plasma Phys. **49**, No.1-2, pp. 15-20 (2009).
[3] P.Hartman, G.J. Kalman, Z. Donko, K. Kutasi, *Phys.Rev. E.,* **72** (2005), P. 026409.
[4] H.Totsuji, M.Liman, C.Totsuji and K.Tsuruta, *Phys.Rev. E.*, **70** (2004), P. 016405.

15th International Conference on the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

PNP

Abstracts of talks

Wednesday 02.09.2015, 9:00 – 12:30

I5: Wednesday 02.09.2015, 9:00 - 9:40

Application of the method of moments in plasma physics: new developments

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The dielectric function of dense equilibrium two-component plasmas constructed within the classical method of moments [1] satisfies all convergent sum rules automatically. Since these sum rules are directly related to the coefficients of the (inverse) dielectric function asymptotic high-frequency expansion, the asymptotic properties of existing alternative models (the extended random-phase and Mermin approximations, the full-conserving model, etc.) are analyzed Some drawbacks and advantages of the above models with respect to the convergent sum rules are pointed out [2].

The influence of the electron-ion coupling in two-component target plasmas on the stopping power [3] and straggling properties of the latter, particularly their asymptotic forms corresponding to high projectile velocities, are studied within the moment approach and the above alternative models of the plasma dielectric function.

A model for the two-component plasma dynamic structure factor free of adjustment parameters is suggested and successfully tested [4] against the simulation data [5].

References

[1] V.M. Adamyan, T. Meyer, I.M. Tkachenko, *Sov. J. Plasma Phys.*, 1985, 11, p 481; T. Meyer, I.M. Tkachenko, *Contrib. Plasma Phys.*, 1985, 25, p 437; V.M. Adamyan, T. Meyer, I.M. Tkachenko, *Contrib. Plasma Phys.*, 2003, 43, p 252; I.M. Tkachenko, Yu.V. Arkhipov, and A. Askaruly, The Method of Moments and its Applications in Plasma Physics (Lambert, Saarbrücken, 2012).

[2] Yu.V. Arkhipov *et al.*, *Phys. Rev. E*, 2014, 90, 053102; *Phys. Rev. E*, 2014, 91, 019903.

[3] D. Ballester and I.M. Tkachenko, *Phys. Rev. Lett.*, 2008, 101, 075002; *J. Phys. A: Math. Theor.*, 2009, 42, 214035.

[4] Yu.V. Arkhipov *et al.*, *Contrib. Plasma Phys.*, 2015, 55(4).

[5] T. Pschiwul and G. Zwicknagel, *J. Phys. A: Math. Gen.*, 2003, 36, p 6251; G. Zwicknagel and T. Pschiwul, *Contr. Plasma Phys.*, 2003, 43, p 393.

T26: Wednesday 02.09.2015, 9:40 - 10:00

Equation of State and transport properties in warm dense matter

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Knowledge about the thermodynamic and transport properties in warm dense matter are crucial for the understanding of astrophysical objects or technical applications in the effort towards the realization of inertial confinement fusion. Also the general interest on the behavior of matter in high energy density physics has been triggered by new experiments. In this context our group's current developments in the theoretical description using Green's function approach and generalized Zubarev formalism will be reported which allow better understanding of new and revisited experiments.
A central issue in the description is the presence of both bound states and free charge carriers. Going beyond the controversal chemical picture, we apply the generalized Beth-Uhlenbeck formula to infer the contributions of bound and scattering states within a cluster virial expansion. The relevance of contributions due to $e - H_2$ interactions [1] for the equation of state is confined to the parameter range where both the H_2 and the free electron components are abundant.
For the transport and optical properties, starting from a generalized linear response approach we bridge between the fluctuation-dissipation theorem and kinetic theory. Instead of a relaxation time approximation, a consistent approach has been given [2] using optimally chosen relevant observables.
Aluminium has been and is currently again of much interest. We have revisited the dc conductivity in the context of a suggested fit formula [3]. It was developed for easier access to electrostatic and thermoelectric transport properties. The relevance of e-e collisions is still a much discussed topic. It will be reported how its influence can be considered for dynamical collisions and leads to a better understanding, e.g. of Thomson scattering experiments or reflectivity measurements. If the system is dimensionally reduced new excitation patterns emerge which can be seen as additional frequency modes [4].
The modification of spectral line shapes in the plasma environment has been considered in particular for hydrogen like emitters or K_α-lines from inner shell transitions [5].

References

[1] Y. A. Omarbakiyeva, H. Reinholz, G. Röpke, Cluster virial expansion of the equation of state for hydrogen plasma with $e - H_2$ contributions, *PRE* **91** (2015) 043103.
[2] H. Reinholz, G. Röpke, Dielectric function beyond the random -phase approximation: Kinetic theory versus linear response theory, *PRE* **85** (2012) 036401.
[3] H. Reinholz, G. Röpke, S. Rosmej, and R. Redmer, Conductivity of warm dense matter including electron-electron collisions, *PRE* **91** (2015) 043105.
[4] T. Raitza, I. Broda, H. Reinholz, G. Röpke, Collective Excitations of Finite-Temperature Nano Plasmas, *Contr. Plasma Phys.* **53** (2013) 263.
[5] Y. Chen, A. Sengebusch, H. Reinholz, G. Röpke, Plasma diagnostics using K -line emission profiles of silicon, *Contr. Plasma Phys.* **54** (2014) 772.

T27: Wednesday 02.09.2015,10:00 - 10:20

Nuclear Quantum Effect on the Structure, Transport Properties, and Melting of Dense Matter

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Structure, transport properties and melting of dense hydrogen and helium are of fundamental significance in astrophysics, planetary science and inertial confinement fusion. Due to the low mass, hydrogen and helium are expected to exhibit significant quantum effects, especially under low temperatures and high pressures. Nuclear quantum effects (NQEs) on structure and transport properties of dense liquid hydrogen and helium [1,2] under extreme conditions are investigated using the improved centroid path integral molecular dynamics (PIMD) simulations combining with DFT as well as high-pressure ice [3]. The results show that with the inclusion of NQEs, the radial distribution functions are obviously broadened. The self-diffusion is largely higher while the shear viscosity is notably lower than the results of without the inclusion of NQEs due to the lower collision cross sections even when the NQEs have little effects on the static structures. Meanwhile, the relation between diffusion and viscosity deviates from the Stokes-Einstein (SE) relation which is valid for Brownian particles, thus the SE relation is not valid in strongly coupled regime. The electrical conductivity is also significantly affected by NQEs. We have shown that the quantum nuclear character induces complex behaviors for ionic transport properties of dense liquid hydrogen and helium. Therefore, in order to construct more reasonable structure and evolution model for the planets and white dwarfs, NQEs must be reconsidered when calculating the transport properties at certain temperature and density conditions. In addition, the melting temperature of dense hydrogen is also investigated using the two-phase approach based on the PIMD with the Yukawa potential describing the interaction between ions. The results show that the NQEs have a significant impact on the melting of dense hydrogen, which largely lower the melting temperature by ~10% at the density range of 10-1000 g/cm^3.

References

[1] Dongdong Kang, Huayang Sun, Jiayu Dai, Wenbo Chen, Zengxiu Zhao, Yong Hou, Jiaolong Zeng, and Jianmin Yuan. *Scientific Reports,* 2014, 4, pp 5484.
[2] Dongdong Kang, Jiayu Dai, Huayang Sun, and Jianmin Yuan. *arXiv:*1502.04554v1 (2015).
[3] Dongdong Kang, Jiayu Dai, Huayang Sun, Yong Hou, and Jianmin Yuan. *Scientific Reports,* 2013, 3, pp 3272.

T28: Wednesday 02.09.2015,10:20 - 10:40

Dynamic and static properties of bosonic dipolar bilayers: The sum-rule approach vs. stochastic reconstruction

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We consider a two-component 2D dipolar bosonic system in the bilayer geometry. The system is translationally invariant in the plane (no optical lattice). By performing quantum Monte Carlo simulations[1] we analyze in detail static distribution functions, kinetic and interaction energies as a function of the interlayer distance. By reducing the layer distance and increase of the interlayer coupling we, finally, observe formation of the dimer states. This transition is accompanied by pronounced changes in the static properties, the off-diagonal (quasi)long-range order (superfluid reponse), as well as in the spectrum of collective density modes.

The diagonal and offdiagonal components of the dynamic structure factor $S_{\alpha\beta}(\omega, q)$ are reconstructed from the imaginary time density response functions via the stochastic optimization method[1]. During the reconstruction several power-moments $\langle \omega^n \rangle (n=-1,0,1,3)$ are satisfied exactly.

The excitation spectrum undergoes a gradual transition between three regimes: i) for large layer separations two independent single-layer spectra, ii) for intermediate distances a strongly hybridized spectrum with two characteristic in-phase and out-of-phase modes, iii) single-layer-like spectrum of quasiparticles (double mass and dipole moment) when a strongly bound dimer states are formed.

The dispersion law for the in-phase and out-of-phase collective modes during this crossover is studied in detail and compared with the predictions based on the sum rules formalism[2,3].

We repeat our analysis for mass-asymmetric bilayers and observe some additional effects which are peculiar for mixtures of light and heavy bosonic species.

References

[1] [1] A. Filinov and M. Bonitz, Phys. Rev. A 86, 043628 (2012)
[2] K.I. Golden, G.J. Kalman, Phys. Rev. E 88, 033107 (2013)
[3] Yu.E. Arkhipov, A. Askaruly, D. Ballester, A.E. Davletov, I.M. Tkachenko, G. Zwicknagel, Phys. Rev. E 81, 026402 (2010)

T29: Wednesday 02.09.2015,11:10 - 11:30

Oscillations and electron emission from laser produced cluster nanoplasma

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The nanoplasma produced by laser pulses of moderate intensities (10^{13} – 10^{16} W/cm^2) targeted at metal clusters is studied by molecular dynamics (MD) simulations. Whereas a lot of the cluster plasma studies are concerned with the Coulomb explosion of the ion core we focus on the electron dynamics just after cluster ionization. In particular we consider electron eigenmodes and electron emission depending on the cluster size and plasma temperature.

One of the distinguishing features of the cluster plasma is the violation of the plasma neutrality [1]. Due to the laser ionization and further thermionic emission from the plasma surface the cluster gains an uncompensated positive charge. With respect to a small number of particles in the clusters under consideration (10-10^6) this charge determines the rate of plasma expansions, affects the rate of ionization-recombination processes, electron density profile, and optical properties of the cluster plasma [1-3].
In this work we propose a model of thermionic emission of nanoclusters based on our MD simulation results [6]. This model qualitatively explains known experimental results [5] and it is in a good agreement with other simulations [4]. The dependency of the electron oscillation spectrum on the cluster charge is discussed. The frequencies and damping rates of different electron eigenmodes including Mie and Langmuir oscillations are obtained.

This work is supported by the Russian Science Foundation, grant No. 14-50-00124.

References

[1] V.P. Krainov, B.M. Smirnov, M.B. Smirnov *Physics-Uspekhi,* 2007, 50 (9), pp 907.
[2] V.P. Krainov, B.M. Smirnov *Physics-Uspekhi,* 2000, 43 (9), pp 901.
[3] Th. Fennel, K. Meiwes-Broer, J. Tiggesbaumker, P. Reinhard, P. Dinh, E. Suraud *Rev. Mod. Phys.,* 2010, 82 (2), pp 1793.
[4] H. Reinholz, I. Broda, T. Raitza, G. Rëpke *Contr. Plasma Phys.*, 2013, 53, pp 263.
[5] R. Rajeev, T. Trivikram, R. Madhu, M. Krishnamurthy *Phys. Rev. A.,* 2013, 87 (5), pp 053201.
[6] R. Bystryi, I. Morozov *J. Phys. B.,* 2015, 48 (1), pp 015401.

T30: Wednesday 02.09.2015,11:30 - 11:50

Transport in Strongly Correlated Plasmas: Influence of Magnetic Fields

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The essential dynamical properties of a strongly coupled plasma include the transport properties diffusion, viscosity, and heat conductivity. Under the influence of an external magnetic field, the symmetry of the system is broken into field-parallel and cross-field transport contributions. At the same time, the strongly correlated particle movements couple these different directions and give rise to a complex dependence on the coupling strength and the magnetic field [1-3].

In this contribution, we discuss these effects for the case of heat conduction in a Yukawa One-Component Plasma. We consider in detail the contributions of material and immaterial transport to the thermal conductivity and how these are influenced by the magnetic field. We also discuss the thermal analogue of the Hall effect and its dependence on the coupling strength and the magnetic field.

References

[1] T. Ott and M. Bonitz, *Physical Review Letters* **107**, 135003 (2011)
[2] T. Ott, H. Löwen, and M. Bonitz, *Physical Review Letters* **111**, 065001 (2013)
[3] T. Ott, H. Kählert, A. Reynolds, and M. Bonitz, *Physical Review Letters* **108**, 255002 (2012)

T31: Wednesday 02.09.2015,11:50 - 12:10

The calculations of thermophysical properties of Fe plasma

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The study of thermophysical data in plasma region for various substances has started more than a century ago [1]. The relatively high plasma temperatures are the main obstacle for measurements in this region for non-alkali metals (T> 5 kK). Usually the plasma state of metals has appeared in experiments with shocks or due to the interaction of radiation or particle beams with a substance. In both processes there is the problem to obtain the equilibrium state. As a result there were many theoretical works devoted to the calculations of various thermophysical properties of non-ideal plasma of metals in the region inaccessible for measurements. But during two past decades several new experiments for plasma of non-alkali metals have appeared [2-4]. They are based on the explosions of metallic wires (or foils) due to the quick heating by electric current. Although the temperature is not measured directly in this process, the data on pressure, internal energy, density and electrical resistivity have been obtained. These new data allows one to check the existing theoretical models.

Earlier we have developed the chemical model for plasma state to calculate the ionic composition, pressure, internal energy etc. Combination of this model with the relaxation time approximation allows us to calculate the electronic transport coefficients (electrical conductivity, thermal conductivity and thermal power). The chemical model uses some approximations for free energy. They give rise to the limitation of the considered approach by density from above. Nevertheless this technique was successfully applied to the plasma of noble gases, noble metals and semiconductors [5-7]. In present report the Fe plasma is studied. Corresponding measurements for Fe plasma are presented in [2, 3] for the conductivity and caloric equation of states (pressure, internal energy, density). The values of the densities and temperatures under study are within the limit of applicability of considered models. I. e. the temperatures (by estimates) are more than 10 kK, while the density is several times less than the normal one. The results obtained by considered approach are in good agreement with the measurement data and the results of calculations obtained by other models.

References

[1] V. E. Fortov, I. T. Yakubov. The Physics of Non-Ideal Plasma. World Scientific (1998).
[2] A. W. DeSilva, G. B.Vunni *Phys. Rev. E*, 2011, 83(3), 037402 (4 pp).
[3] V. N. Korobenko, A. D. Rakhel *Phys. Rev. B*, 2012, 85(1), 014208 (6 pp).
[4] J. Clerouin, P.Noiret et. al. *Phys. Plasmas*, 2012, 19 (8), 082702 (15 pp).
[5] E. M. Apfelbaum *Contrib. Plasma Phys.*, 2011 51 (4), pp. 395 – 400.
[6] E. M. Apfelbaum *Phys Rev. E,* 2011, 84 (6), 066403 (10 pp).
[7] E. M. Apfelbaum *Contrib. Plasma Phys.*, 2013, 53 (4-5), pp. 317– 325.

T32: Wednesday 02.09.2015,12:10 - 12:30

Equations of state and transport properties of mixtures in the warm dense regime

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We have performed average-atom molecular dynamics to simulate the CH and LiH mixtures in the warm dense regime, and obtained equations of state and the ionic transport properties. The electronic structures are calculated by using the modified average-atom model, which have included the broadening of energy levels, and the ion-ion pair potentials of mixtures are constructed based on the temperature-dependent density functional theory. The ionic transport properties, such as ionic diffusion and shear viscosity, are obtained through the ionic velocity correlation functions. The equations of state and transport properties for C, H and Li, H mixtures in a wide region of density and temperature are calculated. Through our computing the average ionization degree, average ion-sphere diameter and transition properties in the mixture, it is shown that transport properties depend not only on the ionic mass but also on the average ionization degree.

15th International Conference on
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PNP

Abstracts of talks

Thursday 03.09.2015, 9:00 – 17:10

I6: Thursday 03.09.2015,9:00 - 9:40

Mixtures of warm dense H, He, and ices,with application to giant planets

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Giant planet interiors carry important information on fundamental questions of relevance to astrophysics and the Earth, such as the formation of planets, the origin of atmospheric dynamics, and magnetic field generation. Our understanding of giant planets is limited by the accuracy by which physical properties of the planetary constituents are known.

Here we present an overview on recent advances on the EOS of H-He mixtures [e.g.,1], water-methane-ammonia mixtures [2], their transport properties such as the diffusion coefficients [2], and phase diagrams [e.g.,3], all essentially derived from first-principles computer simulations. In particular, we show that the commonly used linear mixing approximation works well for non-ideal fluid matter.

Furthermore, we outline key observations that have led -together with the above mentioned progress- to a series of new planet models. Jupiter for instance is suggested to have a thin helium rain zone as indicated by its He-Ne depleted atmosphere [4], while Saturn is argued to be largely inhomogeneous, perhaps as a result of significant H/He demixing [5]. Finally, we find that Uranus' faintness points to an interior of non-ideal water-ammonia-silicate plasma rather than an icy interior.

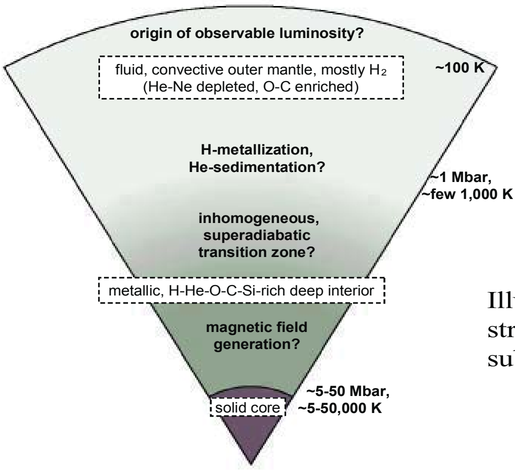

Illustration of giant planet internal structure and open questions subject to current research.

References

[1] A. Becker, W. Lorenzen, R. Redmer et al., *Astrophys. J. Suppl.* (2014) 215:14
[2] E. Meyer, M. Bethkenhagen, N. Nettelmann et al. (2015), *submitted*
[3] M. Morales, S. Hamel et al., *Phys. Rev. B* (2013) 87:174105
[4] N. Nettelmann, J.J. Fortney, K. Moore, C. Mankovich, *MNRAS* (2015) 447:3422
[5] J. Leconte & G. Chabrier 2013, *Nat. GeoSci* (2013), 6:347

T33: Thursday 03.09.2015, 9:40 - 10:00

High Energy Density Physics at GSI and Preparations for the experimental Programme at FAIR in Darmstadt

D.H.H. Hoffmann[1] on behalf of HEDgeHOB[2] Collaboration at FAIR with

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High Energy Density (HED) states in matter can be achieved by pulsed power deposition from intense laser or particle beams. GSI-Darmstadt presently provides the most intense heavy ion beam and a high power laser (PHELIX) for interaction experiments of laser plasma and ion beams. Approximately 200 scientists from 45 institutes and 16 countries worldwide are members of the HEDgeHOB [1] collaboration. They prepare novel experiments at FAIR (Facility for Antiproton and Ion Research) to study thermo-physical, transport, and radiation properties of HED matter, generated by the impact of intense heavy ion- and laser beams on dense targets. Paramount to the success of the research project is the development of cryogenic targets for the beam plasma interaction experiments proposed by the HEDgeHOB collaboration: HIHEX and LAPLAS for the FAIR-start phase. The progress of cryo-target production will be addressed in some detail. For the research topic in general plasma phenomena, phase transitions and equation of state properties of matter are of interest. The proposed experiments will explore the region of the phase diagram which is dominated by strongly coupled plasma and warm dense Matter (WDM).
The current status of the FAIR and efforts of the HEDgeHOB collaboration to prepare for the experimental phase at FAIR will be discussed with emphasis on cryo-target development

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References

HEDgeHOB Collaboration: http://hedgehob.physik.tu-darmstadt.de:

T34: Thursday 03.09.2015,10:00 - 10:20

Strongly Coupled Plasma under External Sources of Ionization

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Strongly Coupled Plasma (SCP) exists in many astrophysical objects, laboratories and applications. Plasma parameter for SCP defined by concentrations of charged particles and temperature, which coupled due to minimum of thermodynamic potential like in Saha equation for ideal plasma. In many cases SCP is created by external sources of ionization, like in ionization from underground Radon gas in low atmosphere and space shower in upper Earth atmosphere [1]. Due to nuclear reactions, X-rays, gamma-and laser radiation, fast particles and photons first create primary electrons, which during their stopping generate first, second and other generations of secondary electrons. The same problem exists in the stopping of charged particles in the ICF experiments. In the last Omega and NIF experiments, the Stopping power in Warm Dense Matter (WDM) has been measured. The main features of SCP under external sources of ionization is that the two main parameters – concentration of charged particles and their mean energy or temperature can be changed independently – concentration of charged particles – by energy and power of external source of ionization and their mean energy or temperature – by external or by applied or creating due to charge separation electric fields. It gives the opportunity to create very dense nonideal plasma.

In the report the examples of SCP under external sources of ionization is considered. Numerical simulations of the secondary generations of electrons are considered by different methods – solutions of Monte-Carlo stories of stopping primary electrons to different generations of secondary electrons and by the solution of Boltzmann equation for both primary and second generations of electrons. In real plasma during stopping plasma penetrate through the volume contains atoms, molecules, particles excited by flow of high energy of electrons and all these processes define the electron energy distribution function of strongly coupled plasma (SCP). We have been performed for different gas mixtures constituted of dense gas of molecules and atoms under influence of high energy electron source, with detailed elementary electron collision processes with molecules and atoms being taken into consideration. The energy expenses of electrons into ionization, dissociation and excitation of various levels have been obtained so that to determine the rates of electron collision processes. The dependence of the electron energy expenses into various inelastic electronic processes upon the energy of primary electron source has been revealed.

Another important issue for externally excited matter and creating plasma that energy distribution is highly non Maxwellian and concentrations and temperature are not strongly coupled like in plasma under thermodynamic equilibrium. It give the new types of waves and instabilities in such plasmas. We considered ambipolar, acoustic, Alven waves in selfsustained electric and magnetic fields.

Experimental installations, basic results and applications are considered.

References

[1] V.P. Konovalov, E.E.Son. Degradation Spectra of Electrons in the Ionosphere J. Plasma Phys. Plasma Conf. Series, Extreme state of matter, Elbrus, Russia, 2015.

T35: Thursday 03.09.2015,10:20 - 10:40

HIGH ENERGY DENSITY PHYSICS AND ION-BEAM PLASMA INTERACTION BASED ON LARGE SCALE HEAVY ION ACCELERATORS IN CHINA

Y. Zhao, R. Cheng, X. Zhou, Y. Wang, J. Deng, Y. Lei, G. Xu, J. Ren, Y. Sun, L. Ma, C. Cao, Q. Zhao, Z. Zhang, L. Sheng, J. Yang, G. Xiao, and W. Zhan
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A large scale scientific research platform, named High Intensity heavy-ion Accelerator Facility (HIAF), was proposed as one of the projects for basic sciences and technologies of the 12th 5-year-plan in China. It will be a lab opening to the outside world, offering additive opportunity for investigating the high energy density (HED) physics and the basic techniques for Inertial Confinement Fusion (ICF) driven by intense heavy ion beam. As shown in Figure 1, the high ion beam intensity would be as high as 10^12 ppp/mm^2, and the terminals for HEDP research would contain a high energy electron beam line and an ion beam line for radiographic diagnostics and particle-plasma interaction studies, in addition to the main pulse for creation of HED.

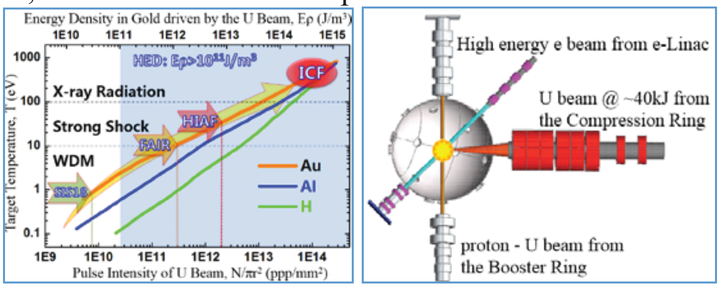

Fig.1 HIAF will offer an additive opportunity to the HEDP community

In addition, we would like to report the progress on the investigation of the energy loss of hundreds keV/u proton and helium beams after passing a gas-discharged plasma target. Figure 2 shows the experimental result for 400keV helium beam penetrating the hydrogen plasma target (with initial gas pressure of 1-8mbar, and discharging high-Voltage of 3kV) in terms of time after discharging.

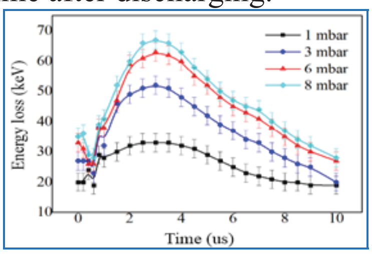

Fig.2 Energy loss of 400keV He in plasma with different initial gas pressure

The work is supported by NSFC (11275241, 11375034).

References

[1] Zhao Y. et al. 2012 Laser and Particle Beams 30 679–706
[2] Cheng R. et al. 2013 Phys. Scr. T156 014074
[3] Y. Zhao, et al, 2014 High Power Laser Science and Engineering, 2, e39.

T36: Thursday 03.09.2015,11:10 - 11:30

Simple Analytical Model of Classical Coulomb Cluster in a Cylindrically Symmetric Harmonic Trap

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Interest to investigation of systems of strongly interacting charged particles manifested since the beginning of the last century. In recent decades, it is primarily associated with studies of nonneutral plasmas and ion crystals, electrons above liquid He and in quantum dots, colloid crystals and significantly in connection with investigations of complex and dusty plasmas. One of the interesting problems is the restructuring of the cluster configuration when the trap anisotropy (relation between the confining forces in the axial and radial directions) is varied. This problem has been considered repeatedly using numerical simulations. However, a model, allowing simple evaluations of the cluster energy, size and form depending of the trap anisotropy, would be useful. Such a model is presented in this contribution.

Classical cluster of charged particles in a cylindrically symmetric harmonic (parabolic) trap is considered. Neglecting the discreteness of its structure and assuming a uniform distribution of particles, we have obtained simple analytical expressions for the cluster size and potential energy in a trap of arbitrary anisotropy. Effect of possible nonuniformity in the particle distribution has been evaluated and shown that it is very weak for the cluster shape and potential energy. We compare the model results with numerical simulation data and show that the model error for 3D clusters is less then that for 2D clusters. The used approximation is obviously valid for sufficiently large number of particles N in the cluster. So, for extension of the model to the smaller clusters, we have introduced correction factors into the expressions for the cluster size and potential energy. In Fig. 1, we present the dependence of the cluster potential energy U per $N^{5/3}$ on the anisotropy parameter α $(\alpha = (dF_z/dz)/(dF_r/dr)$, where F_z and F_r are the confining forces acting in the direction of the symmetry axis z and in the x–y plain respectively, $r^2 = x^2 + y^2$; $E_0 = (q^4 m\omega^2/2)^{1/3}$, q and m are the charge and mass of the particle, ω is the frequency of its oscillations in the x–y plain about the equilibrium position). The curves present results of the model for $N = 13$, 23, 100 and $N > 1000$ (the correction factor becomes unity for $N > 1000$). Symbols show the results of molecular dynamic simulations for $N = 13$ and 23. We see that our model is in a good agreement with numerical simulation even for such small clusters. At $\alpha = \alpha_{2D}$ the 3D–2D transition occurs, so $U = U(\alpha_{2D})$ for $\alpha > \alpha_{2D}$. However, it is impossible to show the 3D–1D transition in the framework of the uniform cluster model, so the curves are cut off at $\alpha = \alpha_{1D}$ where this transition occurs.

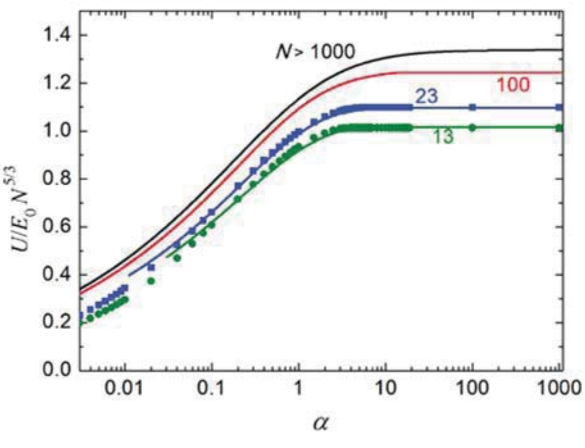

Fig. 1. Potential energy of Coulomb cluster depending on the trap anisotropy. Comparison of the results of the uniform cluster model and numerical simulations.

This investigation was supported by the Russian Scientific Foundation (grant No 14-50-00124).

T37: Thursday 03.09.2015,11:30 - 11:50

Dust solitons in reactive plasma of a spherical glow discharge

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In the paper, we present the results of video observations, measurements and provide an explanation of an intriguing quasi-periodic process of the formation of compact clouds of negatively charged dust nano-particles (radius R_d ~ 100 nm, charge number Z_d ~ 100) in the potential wells of strong striations of a spherical DC glow discharge [1,2]. Nano-particles grew in the reactive discharge due to coagulation of ethanol dissociation products. Periodically, a dust cloud, which formed at the external striation of a spherical discharge, experienced a sudden explosion and split into two approximately equal clouds moving in the opposite directions. The potential energy of dust particles interaction in the initial cloud that was captured in a stratum potential well transformed into the kinetic energy of the two new clouds.

One of these clouds moved to the chamber walls as a compact soliton at “high” velocity. The velocity of this dust cloud was the exponentially decaying function of time as in the case of dissipative dust solitory waves. The other dust cloud moved toward the discharge centre, reflected from inner striations, and returned to the initial position. While the external cloud of nanoparticles was flying away, a new portion of dust nanoparticles began to gather in the striation in the same position, and the process was repeated with the repetition time τ ~ 20-40 s.

We analyzed the dynamics of the dust clouds movement toward the cathode side after the explosions for the following experimental conditions: discharge current I_d = 15 mA, discharge voltage U_d = 500 V, ethanol pressure p = 0.2 Torr. It was obtained that the velocity of dust clouds can be approximated by formula $V_d(t) \approx V_0\exp(-\gamma\ t)$, where $V_0 \approx$ 16.12 cm/s is the initial velocity of the cloud just after the explosion, $\gamma \approx 3.23\ s^{-1}$ is the damping rate, which is surprisingly smaller than the value of Epstein’s damping rate equal to $\gamma_{epsh} \approx 150\ s^{-1}$ [3,4]. It should be mentioned that there have been several experimental studies on the propagation of nonlinear dust acoustic solitary waves [3,4], which showed an unexpectedly low damping rate of soliton velocity. This discrepancy can be explained by the action of an effective electric field E_{eff} that formed inside the dust cloud, which confines negatively charged dust particles in the cloud, prevents them from dispersing, and decreases the damping of the cloud velocity.

References

[1] O.A. Nerushev, S.A. Novopashin, V.V. Radchenko, G.I. Sukhinin. *Phys. Rev. E.*, 1998, **58** (4), pp 4897-4902.
[2] A.E. Belikov, S.Z. Sakhapov. *J. Phys. D: Appl. Phys.*, 2011, **44** (4), pp 45202−45206.
[3] R. Heidemann, S. Zhdanov, R. Sutterlin, H. Thomas, and G. Morfill, *PRL*, 2009, **102**, p 135002.
[4] S. Zhdanov, R. Heidemann, M. Thoma, et al. *EPL*, 2010, **89**, p 25001.

T38: Thursday 03.09.2015,11:50 - 12:10

Influence of ion magnetization on the dust wake potential and the ion-dust streaming instability

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Streaming ions play an important role in complex plasmas because they strongly affect the interaction between dust particles and can give rise to an ion-dust streaming instability [1]. We use a linear response approach to study these questions in a situation where an external magnetic field leads to a strong magnetization of the ions. The dependence of the wake potential on the plasma parameters is investigated in detail -- from weak to strong ion magnetization and slow to fast ions flows [2]. Depending on the flow velocity, magnetizing the ions increasingly suppresses the wake structure (supersonic regime) or strongly modifies the topology of the wakefield (subsonic regime). We further calculate the susceptibility for magnetized ions driven by an external electric field, leading to non-Maxwellian velocity distributions [3], and investigate the influence on the wake potential and the streaming instability.

References

[1] M. Rosenberg, J. Vac. Sci. Technol. A **14**, 631 (1996)
[2] J.-P. Joost, P. Ludwig, H. Kählert, C. Arran, and M. Bonitz, Plasma Phys. Control. Fusion **57**, 025004 (2015)
[3] A. V. Ivlev, S. K. Zhdanov, S. A. Khrapak, and G. E. Morfill, Phys. Rev. E **71**, 016405 (2005)

T39: Thursday 03.09.2015,12:10 - 12:30

A Dusty Plasma in a Non-Self-Sustained Gas Discharge at Atmospheric Pressure

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The interest to the dusty plasma under pressures of order of 1 bar has been raised quite recently and is basically connected with studying the possibility of developing autonomous energy sources on the basis of plasma-dusty structures [1]. The operation of such an energy source is based on a non-ideal plasma created by high energy products of radioactive decay of radionuclide fuel which is micron sized dust particles. The non-self-sustained (NSS) gas discharge controlled by an external electron beam appeared to be most suitable tool for experimental modeling of such plasma. Therefore, the present paper reports the results of the experimental and theoretical studying of the dusty plasma excited by a fast electron beam under atmospheric or higher pressures. Experiments were carried out in Ar at atmospheric pressure with injected CeO_2 1-5 micron size particles. Gas ionization rate of 115 keV e-beam was about $10^{14}cm^{-3}s^{-1}$.
The self-consistent model of the NSS discharge from [2] was modified by taking into account the processes of electron and ion losses owing to the sink to dust particles as well as hydrodynamic equations for the neutral gas. The numerical calculations have showed that levitated disk-like structure, observed in experiment are the dusty component in a liquid state, with the modified nonideality parameter [3] decreasing with the growth of the voltage due to the decrease in dusty cloud density. When the applied voltage grows the width of the dusty cloud increases, which leads to the decrease in the particle density in case the total number of particles is constant. The levitation height of the clouds were determined and compared with experiment.
Total number of dusty particles in discharge volume depends strongly on their radius. At the given density of dust material, gas ionization rate and applied voltage there is critical radius of dust particles above which all the injected particles were deposited at the cathode.
Analytical expressions are obtained for determination of all parameters of the dusty cloud in the NSS gas discharge under uniform volume gas ionization – critical size, theirs charge and number density, depending on gas kind and ionization rate as well as applied voltage. The created analytical theory can be used for estimation of optimal parameters of dusty plasma in the atomic photovoltaic battery.
By this means the self-consistent model of the NSS discharge in noble gases reveals how a trap for dust particles forms.

The work was supported by the State Atomic Energy Corporation “Rosatom” (contract no. H.4x.44.90.13.1107) and a grant from the President of the Russian Federation (no. NSh-493.2014.2).

References

[1] A.V. Filippov, A.F. Pal', A.N. Starostin et al., Ukr. J. Phys., **50**, No.2, 137 (2005).
[2] A.V. Filippov, V.N. Babichev, N.A. Dyatko et al., JETP, 102, 342 (2006).
[3] O.S. Vaulina, S.A. Khrapak, JETP, **90**, 287 (2000).

I7: Thursday 03.09.2015,14:00 - 14:40

Quasi-2D Phase Transitions in Small and Large Plasma-Dust Systems

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A nature of phase transition in quasi-two-dimensional (quasi-2D) dusty plasma structures was studied and the influence of the quasi-2D cluster size (a number of particles in it) on the features of the phase transition was investigated. Experiments and numerical simulation was conducted for the systems consisting of small (~10) and large (~10^3) number of particles.

To investigate the phase state of the system with 7, 18 and 100 particles observed in numerical and laboratory experiments, we used the method based on analysis of dynamic entropy. Numerical modeling of small systems was conducted by the Langevin molecular dynamic method with the Langevin force, responsible for the stochastic nature of the motion of particles with a given kinetic temperature. Calculations were performed for two-dimensional systems with the Yukawa potential of interparticle interaction.

Phase state of systems with the number of elements in the order of 10^3, was studied using the methods of statistical thermodynamics. Here we present new results of an experimental study of the change of translational and orientational order and topological defects, the entropy and the pair interactions at 2D melting of dust cluster in rf discharge plasma. The experimental results have revealed the existence of hexatic phase as well as solid-to-hexatic phase and hexatic-to-liquid transitions. The pair correlation and bond-angular correlation functions, the number of topological defects, the pair potentials and the excess entropy are measured and analyzed. The bond-orientational correlation functions show a clear solid-to-hexatic-to-fluid transition, in perfect agreement with the Berezinskii-Kosterlitz-Thouless (BKT) theory. The spatial distribution of pair interparticle interaction forces was recovered by the original method based on solving the inverse problem using Langevin equations. The measured phase-state points with the theoretical phase diagram of two-dimensional Yukawa system have been obtained.

This work was supported by the Russian Science Foundation (O.F. Petrov, M.M.Vasiliev, K.B. Stacenko, E.V. Vasilieva, M.I. Myasnikov, E.A. Lisin) through Grant No. 14-12-01440).

T40: Thursday 03.09.2015,14:40 - 15:00

Waves in a quasi-2D strongly coupled superparamagnetic dusty plasma

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Superparamagnetic dust grains suspended in a plasma that is immersed in a magnetic field **B** acquire both an electric charge and a magnetic dipole moment. The grains thus interact via combined Yukawa and magnetic dipole-dipole potentials. When **B** is perpendicular to the layer (tilt angle $\alpha = 90^o$) the combined interaction remains isotropic [1], but when **B** becomes tilted with respect to the perpendicular direction the interaction between the grains becomes anisotropic. It also changes from repulsive to partially attractive at a critical tilt angle α_*. We investigate the dispersion of waves in the strongly coupled liquid phase of this system, confining our analysis to magnetic tilt angles $90^o \geq \alpha > \alpha_*$. We combine a theoretical analysis based on the Quasi-Localized Charge Approximation (QLCA) with Molecular Dynamics (MD) simulations. The MD simulations generate fluctuation spectra and provide pair correlation functions, which are needed as input for the QLCA calculations. Our previous work [2] investigated the dispersion of in-plane polarized longitudinal and transverse waves. Here we extend our work to study a more realistic model, where the grains are confined by an external potential and form a slab of finite width. Remarkably, the formation of the slab is strongly affected by **B**; in particular, the width of the slab can in some cases change by orders of magnitude as the tilt angle is varied. Moreover, since the dust grains now can undergo small oscillations perpendicular to the layer as well, there is, in addition to the in-plane modes, an out-of-plane transverse mode. The wave dispersion relations depend on the direction of propagation in the layer, the relative strengths of the magnetic dipole and Yukawa interactions, the tilt angle and the strength of the confining force. Possible experimental parameters for observing the waves are discussed.

In order to understand the anisotropic correlations in the liquid phase we have investigated the lattice structure of the system in the solid phase. We have followed how the lattice structure changes as the tilt angle moves from the perpendicular to the critical angle, by varying the aspect ratio, the rhombic angle and the orientation of the crystal axes to find the lattice structure that corresponds to the minimum interaction energy.

[1] K. I. Golden, G. J. Kalman, Z. Donko and P. Hartmann, *Phys. Rev. B* **78,** 045304 (2008)
[2] P. Hartmann, Z. Donko, M. Rosenberg and G. J. Kalman, *Phys. Rev. E* **89**, 043102 (2014)

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T41: Thursday 03.09.2015,15:00 - 15:20

The Electrostatic Interaction of Two Point Charges in Equilibrium Plasmas within the Debye Approximation

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The paper presents the results of the study of two point-like charge interaction in an equilibrium plasma within the Debye-Hückel approximation [1]. In paper [2] the electrostatic force between two charged macroparticles in a plasma was considered using the Maxwell stress tensor. It was shown that within the Poisson-Boltzmann model two macroparticles with the same charge always repulsed each other in both isothermal and nonisothermal plasmas. Ignatov in [3] deduced the same result (see also [4-6]). In spite of this clear conclusion new papers are regularly published with the statement of the attraction of macroparticles with charges of the same sign in the equilibrium plasma (see, for example, papers [7-9]).

In papers [10,11] the electrostatic interaction force of two macroparticles was calculated on the basis of numerical simulation with the use of the Maxwell tension tensor and the attraction of two similarly charged macroparticles was found. The calculation was performed for the finite cell with an external boundary.

In this paper the electrostatic interaction of two charged macroparticles in the equilibrium plasma is considered within the Poisson-Boltzmann model using the Debye-Hückel approximation [1]. The effect of external boundary conditions for the electric field strength on the electrostatic force is studied. The problem is solved by the method of potential decomposition into Legendre polynomials. It is shown that the effect of attraction of identically charged macroparticles is explained by the influence of the external boundary. When the size of a calculation cell is increased the attraction effect diminished and the electrostatic force is rather well described by the screened Debye-Hückel potential.

References

[1] P. Debye, E. Hückel, *Phys. Zeitschr.*, 1923, 24, pp.185–206.
[2] A.V. Filippov, A.F. Pal’, A.N. Starostin, A.S. Ivanov, *JETP Letters*, 2006, 83 (12), pp.546–552.
[3] J.C. Neu, *Phys. Rev. Lett.*, 1999, 82, pp.1072–1074
[4] J.E. Sader, D.Y.C Chan, *Journal of Colloid and Interface Science*, 1999, 213, pp.268–269.
[5] J.E. Sader, D.Y.C Chan, *Langmuir*, 2000, 16, pp.324–331.
[6] P.K. Shukla, B. Eliasson, *Rev. Mod. Phys.*, 2009, 81, pp.25–44.
[7] F.B. Baimbetov, A.E. Davletov, Zh.A. Kudyshev, E.S. Mukhametkarimov, *Contrib. Plasma Phys.*, 2011, 51, pp.533–536.
[8] A.V. Shavlov, V.A. Dzhumandzhi, *Physics of Plasmas*, 2013, 20, 083707.
[10] V.A. Gundienkov, S.I. Yakovlenko, *JETP*, 2002, 95, pp.864–877.
[11] Yu.V. Petrushevich, *Matem. Mod.*, 2012, 24 (7), pp.13–32.

T42: Thursday 03.09.2015,15:20 - 15:40

Melting of Small Clusters in Dusty Plasma

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The small systems of interacting particles are actively studied in various fields of science and technology, including nanoengineering and materials design. One of the most interesting and important questions about the properties of small systems is the exploration of their phase states and phase transitions. But the classical thermodynamical approach is inapplicable for this problem.

In this case, methods of analysis of dynamical systems appear to be very effective; in particular, the "dynamic entropy", the concept introduced by Shannon [1] and later developed by Kolmogorov and Sinai [2]. The value of the dynamic entropy decreases when the system orders, and its exploration of the phase space becomes more difficult [3]. In this work we use the simple approach for the estimation of the dynamic entropy, which can be easily applied for the analysis of the experiments and for the numerical simulation – the mean first-passage time, "MFPT dynamic entropy" $S(\varepsilon)$ [4, 5].

In present work, the results of the experimental and numerical study of the dynamics of two-dimensional clusters of 7 and 18 particles interacting via the Yukawa potential is presented. Experiments on the melting of quasi-two-dimensional clusters of polystyrene dust particles were carried out in RF discharge in argon. To simulate the obtained systems we used the Langevin molecular dynamics method; for the details see [6].

We have obtained the dependences of the dynamic entropy $S(\varepsilon)$ for the various values of the kinetic temperature of particles in the simulated systems and for the various magnitudes of the "heating" laser power in experiments. Three phase states of the considered small systems are registered: crystal, liquid and transitional. The mechanism of phase transitions in the systems under study is described.

The suggested technique of the analysis of the system dynamics can be applied to the structures as small as desired.

This work was supported by the Russian Science Foundation (project No 14-12-01440).

References

[1] C. E. Shannon, Bell Syst. Tech. J. 27, 379 (1948); 27, 623 (1948)
[2] N. Kolmogorov, Dokl. Acad. Sci. USSR 124, 754 (1959); Y. G. Sinai, *ibid.* 124, 768 (1959).
[3] P. W. Cleary, J. Math. Phys. 30, 689 (1989).
[4] P. Allegrini, J. F. Douglas, and S. C. Glotzer, PRE 60, 5714 (1999)
[5] P. Gaspard and X.-J. Wang, Phys. Rep. 235, 291 (1993)
[6] Complex and Dusty Plasmas, ed. by V. E. Fortov and G. E. Morfill, CRC Press, (2010)

T43: Thursday 03.09.2015,16:10 - 16:30

Coulomb Structure with a Large Number of Particles in the Dynamic Trap at Atmospheric Pressure

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We present the results of simulations and experimental investigations of charged microparticles dynamics in electrodynamic traps in a gas flow at atmospheric pressure. By mathematical simulation we demonstrated a possibility to confine in the linear quadrupole dynamic Paul trap an ensemble of charged dust particles with a strong Coulomb interaction and found regions of a stable confinement. It has been shown that an increase of gas density expanded a region of particles capturing and decreased amplitude of particles oscillations around an equilibrium state. It was revealed that the trap with fixed parameters may confine a limited number of charged particles. Numerical studies allowed finding areas of capturing in a wide range of particle and trap parameters: microparticle charges, masses and densities; trap electrodes voltages and electric field frequencies; gas viscosity.

The possibility of charged microparticles captured by the linear quadrupole Paul trap to form an ensemble with strong Coulomb interaction at atmospheric pressure was experimentally shown. The ordered structure could contain particles of different sizes and charges. The trap could confine a limited number of charged particles. The structures consisted of positively charged oxide aluminum particles with 10-15 microns sizes and hollow glass microspheres with 30-50 microns diameters were formed in the linear trap with electrode placed 13 mm apart. Stable clouds of thousands of oxide aluminum microparticles with sizes of 4-80 microns were observed in the linear trap with electrode placed 30 mm apart.

Our simulations and experimental studies prove the possibility of a linear trap to capture charged microparticles in gas flows. For the first time the capture and confinement of charged microparticles in a linear Paul trap has been experimentally confirmed at atmospheric pressure in air flows with velocity up to 0.5 m/c.

T44: Thursday 03.09.2015,16:30 - 16:50

Simulation of Confined System of Charged Particles by Wave Packet Molecular Dynamics

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The method of Antisymmetrized Wave Packet Molecular dynamics (AWPMD) [1] is an approximate quantum method for numerical simulation of many-particle dynamics. In this method single electron wave functions are expanded in a set of floating Gaussian wave packets [2, 3]. A trial many-body wave function is constructed depending on the quantum statistical properties of the simulated ensemble, for example for fermions (electrons) a single Slater determinant antisymmetrized product is usually used for each spin projection. The resulting equations of motion follow from the variational principle [1].

The unlimited spreading of the Gaussian wave packets and underestimation of the electron-electron and electron-ion collision frequencies are known to be the major problems of the WPMD method [4] when applied to many-particle systems with homogeneous density, for example plasma systems. Although this spreading is a natural effect for the Gaussian wave function in an unrestricted space, the model of an extended system should also provide correct limitations on the density of allowed quantum states, which remains arbitrary when the wave packets are allowed to spread. Traditionally in plane wave quantum bases this limitation on the partition function is achieved by boundary conditions requiring the periodicity of the basis functions. For the Gaussian case, where the periodicity is not directly achievable, none of the applied earlier wave packet localization techniques (harmonic width constraint, fixed width, periodic boundary conditions for width) lead to correct limiting behavior for low density [4, 5].

In this work we study a model plasma system of quantum electrons and classical ions in a 3D confinement potential constructed from harmonic walls and a flat floor in each spatial direction. The matrix elements of the proposed potential with Gaussians were obtained analytically. The confined system constructed this way is an excellent testing ground for AWPMD method, because it poses correct quantum boundary conditions; reduces to textbook many-body quantum oscillator in the limit of no interaction; reduces to uniform quantum gas when the floor size is large. With our 3D implementation we reproduced earlier results [6] showing that the AWPMD method is able to excellently describe the thermodynamics of a confined fermionic system. We show also that for the confined electron-ion system the AWPMD model does not suffer from the unlimited wave packet broadening problem and the electron wave packet parameters perform finite ergodic motion in the available system phase space. A comparison to the classical system in analogous confinement is given. The implementation of the proposed model to simulation of the extended warm dense matter and the limiting behavior with the system size growth are discussed.

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References

[1] D. Klakow, C. Toepffer, P. G. Reinhard, *J. Chem. Phys.*, 101:10766 (1994)
[2] A.A. Frost, *J. Chem. Phys.*, 47:3707 (1967)
[3] I. V. Morozov and I. A. Valuev, *Contrib. Plasma Phys.,* 52:140 (2012)
[4] I.V. Morozov, I. A. Valuev, *J. Phys. A,* 42:214044 (2009)
[5] P.E. Grabowski, A. Markmann, I.V. Morozov, et al, *Phys. Rev. E,* 87:063104 (2013)
[6] H. Feldmeier, J. Schnack, *Rev. Modern Phys.,* 72:655 (2000)

T45: Thursday 03.09.2015,16:50 - 17:10

Computer simulation of the cage correlation functions of Yukawa liquids

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In various physical settings complex plasmas are affected by external electric and magnetic fields. In particular, the influence of magnetic fields on strongly coupled dusty plasmas became an important topic in the last few years [1,2].

The purpose of this work is to investigate the cage correlation functions [3] in a dusty plasma exposed to a static homogeneous external magnetic field. Computer simulations of motion of the dust particles, interacting via a Yukawa potential (characterized by a screening parameter κ), have been carried out based on both the Newtonian equation of motion and the Langevin equation of motion, which takes into account the influence of buffer gas/plasma environment on the dust particles' dynamics.

Calculations of the cage correlation functions of the two-dimensional and three-dimensional Yukawa systems have been performed for a wide range of the system parameters, coupling: Γ, screening: κ, normalized magnetic field strength $\beta = \omega_C / \omega_P$, where ω_C and ω_P, respectively, are the dust cyclotron and plasma frequencies. Figure 1 illustrates the results for Γ=10, κ=1, at different values of $\beta = \omega_C / \omega_P$; we observe that an increasing magnetic field prolongs the caging time, i.e. the surroundings of the particles change on a longer time scale.

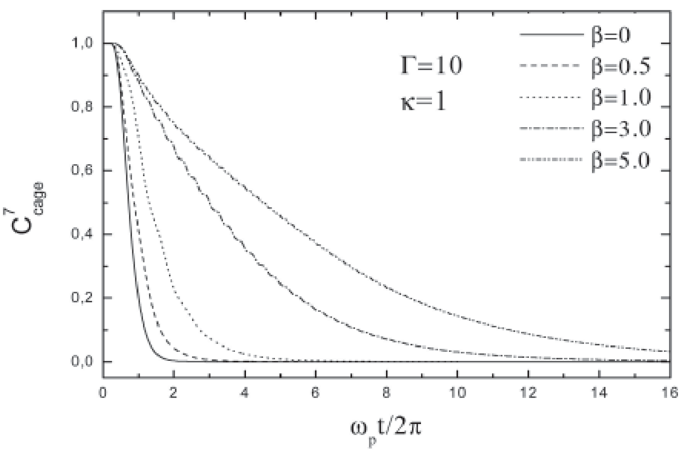

Fig.1 Cage correlation functions of 3D Yukawa liquids characterized by Γ=10 and κ=1, at different normalized magnetic field strengths $\beta = \omega_C / \omega_P$. (Results of Newtonian simulations.)

References

[1] P. Hartmann, Z. Donkó, T. Ott, H. Kählert, and M. Bonitz, Phys. Rev. Lett., 2013, 111, 155002
[2] M. Bonitz, Z. Donkó, T. Ott, H. Kählert, and P. Hartmann, Phys. Rev. Lett., 2010, 105, 055002
[3] Z. Donkó, G. J. Kalman, and K. I. Golden, Phys. Rev. Lett. 2002, 88, 22500

15th International Conference on the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

PNP

Abstracts of posters: Session II

Thursday 03.09.2015, 17:10 – 19:10

- production of non-ideal plasmas (using optical lasers, free electron lasers, heavy-ion beams, Z machine, high explosives etc.)
- equilibrium properties, equations of state and phase transitions – Part 2
- kinetics, transport and optical properties
- dusty plasmas – Part 2

Nr	Name	Surname	Title of Contribution
P2.1	Anuar	Zhukeshov	Materials surface treatment using of pulse plasma flow accelerators
P2.2	Abdiadil	Askaruly	Correlation functions in dusty plasmas with finite-size grains
P2.3	Igor V.	Lomonosov	Equations of state of metals in WDM region
P2.4	Zara	Mazhit	The Ionization Degree of Partially Ionized Hydrogen Plasmas
P2.5	Claudia-Veronika	Meister	Heat capacity of non-ideal plasmas in density order two
P2.6	Nikita	Stroev	Study of Non-Congruent Phase Transition in Simple Coulomb Model
P2.7	Olga	Vaulina	The Influence of Nonlinearity of Pair Interaction Forces on the Melting of Yukawa Systems
P2.8	Oldřich	Živný	Thermodynamic functions of multicomponent thermal plasma at high temperatures
P2.9	Samat	Amirov	Effective Potentials and Scattering Processes in Partially Ionized Dense H-He Plasmas
P2.10	Valery	Karakhtanov	Corrections to the Electrical Conductivity of a Fully Ionized Plasma at Moderate Values of Degeneracy Parameter
P2.11	Tolegen	Kozhamkulov	Problems and perspectives of QCD for description of a quark-gluon plasma properties
P2.12	Chengliang	Lin	Plasma Spectral Line Profiles via Open Quantum System Approach
P2.13	Zhanar	Mukash	Plasma treatment of ZnO:B nanostructured layers synthesized by hydrothermal route
P2.14	Zhanar	Mukash	Influence of hydrogen plasma treatment on the electrical, optical and structural properties of ZnO:B thin films
P2.15	Yultuz	Omarbakiyeva	Optical reflectivity of shock compressed xenon plasma
P2.16	Erik	Shalenov	Influence of dynamic screening on the scattering cross sections of the particles in the dense nonideal plasmas of noble gases
P2.17	Kunduz	Turekhanova	Investigation of Effect of Runaway Electrons in NonIdeal Plasma on the Base of Dynamic Interaction Potential
P2.18	Sergey	Antipov	Dynamic behaviour of polydisperse dust system in cryogenic gas discharge complex plasmas
P2.19	Sandugash	Kodanova	The Dust Particle Dynamics in the Edge Fusion Plasma
P2.20	Sandugash	Kodanova	Ion-Dust and Dust-Dust Scattering Processes in Complex Plasmas
P2.21	Sagi	Orazbayev	Spectroscopic diagnostics of Ar/CH4 and Ar/C2H2 complex plasma
P2.22	Sergey	Pavlov	Method of control of ion drag force in dusty plasmas
P2.23	Sergey	Popel	Charged Dust Motion in Dust Devils on Earth and Mars
P2.24	Gennadiy	Sukhinin	Polarization of Dust Particles surrounded by a Cloud of Trapped Ions in an External Electric Field
P2.25	Elena	Vasilieva	Global orientational order parameter in the two-dimensional Yukawa systems

P2.1

Materials surface treatment using of pulse plasma flow accelerators

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Results of recent studies in Belarusian (V.V. Uglov , A.K. Kuleshov), Poland (J. Langner and coauthors) and Ukrainian (V.I. Tereshin and coauthors) pulsed plasma accelerators [1-3] have shown, that materials processing by high-energy fluxes leads to significant changes of the microstructure and phase composition (selection of small dispersion secondary phase, the formation of metastable phases, etc.).
Our results obtained on the CPA -30 pulsed plasma accelerator show, that on the common construction steel samples, modified layers formation, as a result of the non-equilibrium processes at high speeds cooling (10^5-10^7 K/s), high-energy flux melting of thin (1-10 μm) surface layer materials, undo plasma flow action . Also, we have previously shown, that the plasma parameters generated by pulsed plasma accelerator CPA-30, greatly depend on the geometry of the electrodes and the method of acceleration. But even close on the principle of operation of the devices, operating voltage, the characteristic time of discharge, the plasma density, and others may be different. In this case, there is a question, under what combination of parameters, improvement of the physical properties and processing parameters is achieved. Finally, what are the benefits of material hardening? To answer these questions, this paper analyzes the properties of constructional materials, treated on the plasma accelerator CPA-30, and sowing the principal new technological applications of pulsed plasma accelerators.
The results of development of resource-saving, environmentally friendly technologies for creating products of construction and tool steels and alloys with given properties of surface are presented. This effect can be achieved using pulsed plasma accelerator for surface processing, which are more effective and economical than the stationary plasma systems. After pulsed processing of material surface by plasma, subsurface layers with new properties, consisting of modified structure, were formed. Physical testing showed that after the processing of working surfaces of construction steels the hardness increased up to 300%. The dependence of different factors on modification process and the reason of hardening of constructional materials are discussed.

References

[1] V.V. Chebotarev, I.E. Garkusha, J. Langner M. Sadowski, W. Starosta, V.I. Tereshin, N.T. Derepovski, Surface Structure Changes Induced by Pulsed Plasma Streams Processing," *Plasma Physics,* Vol.3, No 3, 1999, pp. 273-275

[2] Uglov V.V., Kuleshov A.K., Soldatenko E.A., Koval N.N., Ivanov Yu.F., Teresov A.D. Structure, phase composition and mechanical properties of hard alloy treated by intense pulsed electron beams. //Surface and Coatings Technology, Vol. 206, Iss. 11–12, 2012, P. 2972-2976.

[3] Ivanov Y., Petrikova E., Cherenda N., Teresov A. Hardening of the Surface Layer of Silumin by Electron Beam. //Advanced Materials Research Vol. 872 (2014). P. 162-166.

[4] Tereshin V.I. at al. Pulsed plasma accelerators of different gas ions for surface modification. // *Rev. Sci. Instrum.* – 2002. -V.73. - №2. - P.1- 3.

P2.2

Correlation functions in dusty plasmas with finite-size grains

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An ordinary dusty plasma is a classical strongly coupled system whose experimental behavior is routinely visualized. This makes it possible to verify known approaches of the physics of many body systems against the simulation and experimental data already available. To describe the dusty plasma properties it is thus essential to derive an interaction potential of two isolated dust particles. To do so the dielectric medium approximation is employed assuming that a certain pair of grains is immersed into a plasma medium playing the role of a polarizable background. Consequently, the pairwise interaction potential $\Phi(r)$ depends on the distance r as [1]:

$$\Phi(\mathbf{r}) = \frac{1}{(2\pi)^3}\int \frac{\tilde{\varphi}(k)}{\varepsilon(k,0)} \exp(i\mathbf{kr})d\mathbf{k}.$$

Here $\varepsilon(k,0)$ denotes the static dielectric function of the plasma medium and $\tilde{\varphi}(k)$ stands for the Fourier transform of the interaction potential in a vacuum.

Under ordinary experimental conditions the plasma is in an ideal gas state which fully justifies the application of the random-phase-approximation expression for the static dielectric function of the form

$$\varepsilon(k,0) = 1 + \frac{1}{k^2 r_D^2},$$

where r_D designates the Debye screening radius due to electrons and ions of the plasma. In $\tilde{\varphi}(k)$ we take into account the finite-size effects [2] which are of significance when the grain number density grows. On the basis of such an approach analytical expressions are obtained for the interaction potentials between the electrons and ions on the one hand and the grain on the other. Moreover, a new analytical expression is derived for the intergrain interaction potential in a plasma which provides an opportunity for application of various theoretical methods and computer simulation techniques to study intrinsic properties of the dust component. In particular, the Ornstein-Zernike relation in the hypernetted-chain approximation is used to evaluate the radial distribution function of the dust particles which demonstrates a non-monotonic behavior in a specified domain of plasma parameters.

References

[1] A. Davletov. *J. Phys. A: Math. Gen.*, 2006, 39, pp 4555-4559.
[2] A.E. Davletov, L.T. Yerimbetova, Ye.S. Mukhametkarimov, A.K. Ospanova, *Contrib. Plasma Phys.*, 2015, 55, pp 180-185.

P2.3

Equations of state of metals in WDM region

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We present wide-range semi-empirical EOS model for metals. It fully assigns the free energy thermodynamic potential for metals over entire phase diagram region of practical interest. The model accounts for solid, liquid, plasma states as well as two-phase regions of melting and evaporation. Novel experimental data in warm-dense-matter (WDM) region are discussed. They include results of dynamic experiments on shock compression and isentropic expansion of solid and porous metals and information, obtained under conditions of heating by powerful electric current. We present comparison with isobaric expansion, isochoric plasma vessel and “sandwiched” foil experiments for Al, Ti, Fe and W and discuss their consistency with shock-wave data.

P2.4

The Ionization Degree of Partially Ionized Hydrogen Plasmas

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Partially ionized plasmas are objects in many experimental and theoretical researches [1]. In classical plasmas an interaction between charged particles obeys Coulomb's law at large distances. At small distances between charged particles the Coulomb potential diverges. At small distances one should consider a movement of particles, which interact by Coulomb force, taking into account quantum effects. So at classical consideration of plasma besides average distance among particles one should suggest short-range repulsive forces radius. By including short-range repulsive forces at small distances between charged particles plasma medium is considered as quasiclassical system of particles.

At investigation of thermodynamical and structural properties of partially ionized plasma it is of importance to know its ionization degree, besides it substantially influences on radial distribution functions and structural factors of particles, as well on the pressure and the internal energy of the plasma [2].

The ionization degree of partially ionized quasiclassical hydrogen plasma is determined within pseudopotential model of plasmas [1]. To determine the ionization degree the most consistent is an approach, based on the condition of thermal ionization equilibrium of the system of particles: the system of particles is at the state of thermal ionization equilibrium, if its free energy (the Helmholtz potential) takes minimal magnitude, doesn't grow. At minimal free energy the ionization degree is determined. Simultaneously plasma particles interaction macropotentials (pseudopotentials) are obtained by solving Boltzmann-Poisson equations system. Minimal magnitude of the density parameter is estimated from Mott's condition [3].

Given model includes both charge screening and quantum effects of diffraction at short distances. The model of partially ionized hydrogen plasmas allows one to get correct magnitudes of the ionization degree. A comparison of the ionization degree graphical dependences on plasma parameters such as the density parameter and the coupling parameter is accomplished for various approaches: the Saha equation of ionization equilibrium with taking into account the ionization potential decrease in consequence of quantum effects [3] and results of this work. It is shown, that in consequence of the effect of screening for values of the coupling parameter up to one and not large values of the density parameter up to fifteen the ionization degree of partially ionized plasma raises. Quantum diffraction effects follow by the decrease in the degree of ionization of the plasma.

References

[1] Yu.V.Arkhipov, F.B.Baimbetov and oth. *Pseudopotential Theory of Dense High-temperature Plasmas*. Almaty: "Kazakh University", 2002. (In Russian)

[2] Yu.V.Arkhipov, F.B.Baimbetov, A.E.Davletov *Chech. J. Phys.*, 2005, 56, pp 618-623.

[3] W.Ebeling, D. Kremp and oth. *Theory of Bound States and Ionization Equilibrium*. Berlin: Akademic-Verlag, 1976.

P2.5

Heat capacity of non-ideal plasmas in density order two

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To describe the heat transport in dense astrophysical and laboratory plasmas, also the knowledge of the heat capacity of the matter is necessary. In the present work, the heat capacity is calculated within the frame of the thermodynamics of non-ideal plasmas. In doing so, a virial expansion of the equation of state beyond the Debye-Hückel theory is taken into account. Contributions to the heat capacity up to a density order 5/2 are considered. Simple analytical approximations of the heat capacity for the plasma of stellar cores are derived, but also first careful numerical results for the solar interior are obtained.

P2.6

Study of Non-Congruent Phase Transition in Simple Coulomb Model

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Non-congruent (or incongruent) phase transition (NCPT [1,2]) is under discussion in its application to non-ideal Coulomb systems. The modified version for the model of Binary Ionic Mixture on uniformly compressible electron-gas background (BIM(~)) [2,3] was used as the base for development of the most simple and transparent realization of NCPT in Coulomb system. The analytical approximation of Potekhin and Chabrier [4] was used for description of the ion-ion Coulomb correlations (non-ideality) in combination with Linear Mixing Rule (LM) approximation. Parameters of phase equilibrium for the charged components (electrons and ions) were calculated according to the Gibbs-Guggenheim conditions [1]. Features of this simplest variant of NCPT (e.g., dimensionality and topology of phase boundaries, properties and location of critical and end points *etc.*) were calculated and compared with NCPT in chemically reacting plasmas and with NCPT of gas-liquid type in ultra-dense nuclear matter [5]. Remarkable two-dimensional "banana-like" structure was calculated for NCPT two-phase region in P–T plane. Parameters of critical points line (CPL) were calculated within entire range of ionic composition $0 \le X \le 1$ including two reference values, when CP coincides with one of two extreme end-points of maximal temperature (X_T) and pressure (X_P) at the boundary of non-congruent two-phase region. Remarkable behavior of isotherms within two-phase region have been reproduced for whole temperature range $0 \le T \le T_{\max}$. Finally, the typical low-temperature property of non-congruent phase transitions, "distillation", was obtained and compared with similar distillation in NCPT in ultra-dense nuclear matter [5] and with less pronounced this effect in chemically reactive plasmas [1,2].

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References

[1] I. Iosilevskiy, G. Hyland, E. Yakub, C. Ronchi *Int. Journ. Thermophys.*, 2001, **22,** pp 1253.

[2] I. Iosilevskiy *Thermodynamics of non-ideal plasmas,* in: “Encyclopedia of Low-Temperature Plasma Physics” (Suppl. B, V.III-1), Eds. A.Starostin and I.Iosilevskiy, Moscow: Fizmatlit, 2004, PP.349-428 (*in Russian)*

[3] I. Iosilevskiy, *High Temperature,* 1985, **23**, pp 807 // arXiv:0901.3535

[4] A. Potekhin and G. Chabrier, *Phys. Rev.* **E** 2000, **62,** pp 8554 // **E** 2009, **79**, 016411.

[5] M. Hempel, V. Dexheimer, S. Schramm and I. Iosilevskiy, *Phys. Rev. C,* 2013, **88**, pp 014906.

P2.7

The Influence of Nonlinearity of Pair Interaction Forces on the Melting of Yukawa Systems

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We present the numerical and theoretical analysis of melting conditions of crystal lattices in two- and three-dimensional Yukawa systems of charged grains. The values of the coupling parameter of the systems under study on the melting line are presented depending on the screening parameter of the grains. The calculations of the characteristic frequencies and the energies of the lattices were done with the help of the nearest neighbours approximation, and oscillation amplitudes of the grains in the lattice nodes were normalized by the theoretical values of the Lindemann parameters on the melting lines of the structures under study [1-3]. We considered the classical approach of harmonic oscillations, as well as the nonlinear (anharmonic) effects of the pair interaction forces and the concentration of the interacting grains on the positions of the equilibrium phase boundary curves.

Unlike the existing empirical and half-empirical approximations for the boundary curves [3-7], the model proposed in the present work has a simple theoretical explanation and allows to correctly predict the melting conditions for the systems of particles with various isotropic interaction potentials. The obtained results were compared to the existing theoretical and numerical data.

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References

[1] Vaulina O.S., Vasilieva E.V., Petrov O.F. and Fortov V.E., EPL. 2011. V. **96**. 65003.
[2] Dubin D. H. and Dewitt H., Phys. Rev. B **49**, (1994) 3043.
[3] Vaulina O.S., Vasilieva E.V., EPL. 2011. V. **95**. 55004.
[4] S. Hamaguchi, R. T. Farouki, and D. H. E. Dubin, Phys. Rev. E **56**, 4671 (1997).
[5] Vaulina O. S. and Khrapak S. A., *JETP* **90**, (2000) 287.
[6] P. Hartmann, G. J. Kalman and Z Donko, J. Phys. A: Math. Gen. **39** 4485–4491 (2006)
[7] X. H. Zheng and J. C. Earnshaw 1998 Europhys. Lett. **41**(6) 635-640

P2.8

Thermodynamic functions of multicomponent thermal plasma at high temperatures

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The concept of the individual particles with internal degrees of freedom and mutually interacting via intermolecular forces represents basis of so called chemical picture [1]. In this framework, hamiltonian of the system is often considered as to be separable into part representing internal degrees of freedom of the individual particles and part representing mutual interaction, which allows to factorize partition function (PF) making it possible to introduce concept of standard thermodynamic functions (STF) of individual substances, as adopted in chemistry. The main difficulty, which becomes apparent at higher temperatures, consist in the fact that the eigenvalue spectrum of atomic or molecular electronic bound states has infinitely many terms with an upper bound. Consequently, internal partition function as a sum over discrete states tends to infinity making STF also infinite. In order to overcome this difficulty, many approaches of renormalization was developed over the years [2–5].
In the approach considered here, each eigenstate of the particle is regarded as an independent particle, while the maximum term method in distribution function as originally introduced by Gibbs is still valid. The minimization of the macroscopic thermodynamic potentials of the whole system at given temperature and volume, or pressure, within the domain satisfying mass balance constraints for all members of discrete eigenvalue spectrum leads to the finite thermodynamic functions of the system even if the eigenvalue/eigenvector spectrum of the atomic/molecular hamiltonian has infinitely many terms. This method is applicable for both interacting and non-interacting system without an additional condition on renormalisation function or ionization potential lowering.

References

[1] D. Kremp, M. Schlanges, W.-D Kraeft, Quantum Statistics of Nonideal Plasmas (Springer, Berlin, 2005).
[2] M. Planck, *Ann. Physik* **75** (1924) 673.
[3] E. Fermi, *Z. Physik* **26** (1924) 54.
[4] M. Capitelli and Giordano, *Phys. Rev. A* **80** (2009) 032113.
[5] W. Däppen, L. Anderson and D. Mihalas, *Astrophys. J.* **319** (1987) 195.

P2.9

Effective Potentials and Scattering Processes in Partially Ionized Dense H-He Plasmas

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In this work the effective interaction potentials of the charged particles with the helium atom and scattering processes in the partially ionized dense plasma consisting of hydrogen and helium atoms are studied. It is important to study the partially ionized dense plasma consisting of hydrogen and helium atoms as these two elements are widespread in the universe and such a plasma is important for understanding of the evolution of giant planets, stars etc.
As it is known, at high densities the manifestation of the quantum effects must be taken account in the effective interaction potential. We construct new interaction model for H-He plasmas taking into account the effect of atom polarization and the effect of partial screening of the nuclear field by the bound electrons [1, 2]. Here, the screening effect is taken into account within random phase approximation. The bound electrons of helium are described using the known accurate wave function [1] and the atom polarization effect is taken into account within the multipole expansion approximation. As a result new effective screened potentials for pairs of helium atom-charge, and single ionized helium atom-charge are proposed. Using this potential partial, total and transport cross sections have been calculated by solving the Calogero equation for the e-He and e-He+ scattering[2].

References

[1] M. Goldberger and K. Watson, Collision Theory Wiley, New York, 1964, p. 750.
[2] T. S. Ramazanov, K. N. Dzhumagulova, and M. T. Gabdullin, Phys. Plasmas 17, 042703 (2010)
[2] T.S. Ramazanov, K. N. Dzhumagulova, Y.A. Omarbakiyeva, and G. Repke. *Contrib. Plasma Phys.* **47**, 267 (2007).

P2.10

Corrections to the Electrical Conductivity of a Fully Ionized Plasma at Moderate Values of Degeneracy Parameter

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The construction of interpolation formulas for the fully ionized plasma electrical conductivity [1-3] is important as a base for the description of a more complex plasmas transport properties. The interpolation should enter the correct asymptotic limits. In previous works the limits of non-degenerate [4] and strong-degenerate [5] plasmas were investigated with the careful accounting of electron-electron scattering.

In the present work the behavior of correlation functions for electron-ion and electron-electron scattering is investigated as a function of degeneracy parameter $\Theta=k_BT/E_F$ in the region from $\Theta>>1$ to $\Theta\rightarrow1$. The enhanced approximation formulas are presented.

The consideration basis is the following: the linear response theory in the formulation of Zubarev [6], the Lenard-Balescu-type collision integrals [7] with the dynamical screening of Coulomb interaction, the first Born approximation in the thermodynamic Green's functions technique.

References

[1] A. Esser, G. Röpke *Phys. Rev.,* 1998, E58, pp 2446-2455.
[2] A. Esser, R. Redmer, G. Röpke *Contrib. Plasma Phys.,* 2003, 43 (1), pp 33-38.
[3] S. Ichimaru, S. Tanaka *Phys. Rev.,* 1985, A32, 1790-1798.
[4] V.S. Karakhtanov, R. Redmer, H. Reinholz, G. Röpke *Contrib. Plasma Phys.,* 2013, 53, pp 639-652.
[5] V.S. Karakhtanov *J. Phys.: Conf. Series,* 2014, 529 (012017), pp 1-5.
[6] D.N. Zubarev *Nonequilibrium Statistical Mechanics* (New York: Plenum), 1974.
[7] C.-V. Meister, G. Röpke *Ann. Phys.,* 1982, A494, pp 133-148.

P2.11

Problems and perspectives of QCD for description of a quark-gluon plasma properties

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Quark-gluon plasma is a state of matter in which the density and (or) the temperature is so high that ordinary particles (the nucleons, pions, etc) break down into their components, quarks and gluons. Under normal conditions there are not free quarks and gluons, they are always bounded in hadrons, but at very high energies the color "comes to freedom" and hadron matter becomes neutral quark-gluon plasma. It can be realized in the depths of the neutron stars. In terrestrial conditions, the quark-gluon plasma can be formed for a short time during collisions of particles at very high energies.

Currently, a theoretical study of the quark-gluon plasma is carried out using non-perturbative quantum chromodynamics (QCD). It should be noted that for the calculation of nonperturbative effects in QCD the Monte Carlo method is intensively used. An alternative approach to a quantitative description of QCD is based on the method of stochastic quantization. On the one hand it allows to do (sometimes much faster) the same calculation on the computer as the Monte Carlo method does, and on the other hand, it allows to do more deep theoretical analysis, because this method relies on dynamic differential equations.

The basis of the method of stochastic quantization is a formal analogy of problems solved in classical statistical physics and quantum theory. In statistical physics the correlation function can be calculated by using a Gibbs distribution, or from first principles, ie solution of the classical equations of motion for the system, immersed in the thermostat (the Langevin equation), the statistical averages of physical quantities are obtained by averaging over a large period of time.

In the present work the general scheme of stochastic quantization of nonlinear systems in which dynamic variables changed in a Riemannian space was described. Stochastic differential equations of higher orders were developed. The hybrid Langevin equation was proposed. Stochastic quantization in detail was developed in relation to QCD. On its basis the mass spectrum of mesons was determined for the quark-gluon plasma.

P2.12

Plasma Spectral Line Profiles via an Open Quantum System Approach

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A new approach to spectral line profiles in plasmas is given by means of a quantum master equation (QME) for a radiating atom coupled to a surrounding plasma. We derive expressions for a line profile which contain different contributions to the line shape. A comparison with a quantum statistical Green's function approach is performed. The QME approach allows one to investigate different approximations, in particular the Born-Markov approximation for a system weakly coupled to its surroundings. The rotating wave approximation (RWA) is always performed in order to render the QME in the Lindblad form. These approximations are compared with the corresponding approximations in the Green's function approach. Improvements for the RWA are given.

The QME opens the possibility to introduce robust states, for instance wave packets, which are of interest in performing the quasi-classical limit. This is of relevance if the ion contributions are evaluated. As a particular example, Rydberg atoms are considered [1]. Transition rates obtained from the QME approach are compared with simulation data.

References

[1] C. Gocke, G. Roepke, *Theo. Math. Phys.*, 2008, 154, pp 26-51.

P2.13

Plasma treatment of ZnO:B nanostructured layers synthesized by hydrothermal route

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At present, zinc oxide due to its unique physical characteristics becomes an important material for use in short-wavelength light-emitting diodes, detectors, piezoelectric devices, power electronics and many other applications. In particular, ZnO thin films doped with boron is used as a transparent and conductive facial contact of solar cells based on different materials.

One of the most common, low-cost and effective synthesis methods of the different ZnO nanostructures are hydrothermal and sol-gel methods. For the preparing of ZnO structures with required electrical and optical properties is used doping by impurity atoms. In this paper, hydrothermal synthesis of ZnO:B nanorods was performed according to the low temperature technique [1, 2].

The influence of plasma treatment on the electric, optical properties and photoluminescence (PL) spectra of ZnO:B thin films grown on glass substrates was studied. It was found that hydrogen plasma treatment lead to the recovery of the electrical characteristics of ZnO:B samples after degradation caused by thermal annealing in air. Free carrier mobility was especially sensitive to the hydrogen plasma treatment. It is noted that in the hydrogen plasma treatment dramatically increases the intrinsic PL intensity in ZnO:B samples. The initial PL spectra consist of a weak band's own interband luminescence and the impurity band at 550-600 nm. H-plasma treatment causes a significant increase in the intensity of the own photoluminescence more than two orders.

References

[1] Chin-Hsien Hung, Wha-Tzong Whang *Materials Chemistry and Physics*, 2003, 82, pp 705–710.
[2] Zhong Lin Wang *Materials Science and Engineering R*, 2009, 64, pp 33–71.

P2.14

Influence of hydrogen plasma treatment on the electrical, optical and structural properties of ZnO:B thin films

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Currently ZnO is one of the most actively studied wideband (~ 3.37eV) semiconductor materials. Large exciton binding energy (~60 meV) does zinc oxide promising to create a new generation of light optoelectronic devices such as light-emitting diodes based on heterostructures [1] and homostructures [2,3].

In this paper the effect of plasma treatment on electrical parameters, optical transmission spectra, Raman spectra and photoluminescence (PL) spectra of ZnO:B samples prepared by MOCVD on glass substrates was studied.

A change in the electrical properties of the PL spectra of ZnO samples under thermal annealing in air and in vacuum and the effects of plasma treatment in hydrogen was found. A slight recovery of the carrier concentration, the resistivity of the samples and a sharp increase in the PL intensity was observed at a short-term treatment in hydrogen plasma. PL intensity increased about 100 times. This intensity increase of photoluminescence is related to the hydrogen passivation of nonradiative recombination centers such as impurity and structural defects.

References

[1] M.-C. Jeong, B.-Y. Oh, M.-H. Ham, J.-M.Myoung *Appl. Phys. Lett.*, 2006, 88, P 202105.
[2] F. Zhuge, L.P. Zhu, Z.Z. Ye, D.W. Ma, J.G. Lu, J.Y. Huang, F.Z. Wang, Z.G. Ji, S.B. Zhang *Appl. Phys. Lett.*, 2005, 87(9), P 092103.
[3] S.J. Jiao, Z.Z. Zhang, Y.M. Lu, D.Z. Shen, B. Yao, J.Y. Zhang, B.H. Li, D.X. Zhao, X.W. Fan, Z.K. Tang *Appl. Phys. Lett.*, 2006, 88(3), P. 031911.

P2.15

Optical reflectivity of shock compressed xenon plasma

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Experiments with an explosively driven generator of shock waves [1] provides new data for the reflectivity of xenon plasma at pressures 10.5-12.0 GPa and temperatures around 30000 K. Laser beams with wavelengths 1064 nm, 694 nm and 532 nm were used. The reflectivity of s and p- polarization is obtained for various incident angles, showing the Brewster minimum for p-polarization.

The experimental data for the reflectivity were described solving the Helmholtz equations. As input quantity, the complex dielectric function was calculated as function of temperature and density using a quantum statistical approach to the dynamical collision frequency. Both the density and the temperature are depending on position relative to the shock front. The experimental data are reproduced using a Fermi-like density profile [2, 3].

New data are presented and a more general description of the reflectivity data is found including the contribution of atoms.

References

1. V. B. Mintsev, Yu. B. Zaporozhets, *Contrib. Plasma Phys.,* 1989, 29, p. 493.
2. M. Winkel, H. Reinholz, A. Wierling, G.Röpke, Y. Zaporozhets, and V. Mintsev, *Contrib. Plasma Phys.,* 2009, 49, pp. 687 – 691.
3. T. Raitza, H. Reinholz, G. Röpke, V. Mintsev and A. Wierling, *J. Phys. A: Math. Gen.,* 2006, 39, pp. 4393–4399.

P2.16

Influence of dynamic screening on the scattering cross sections of the particles in the dense nonideal plasmas of noble gases

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In work [1] the effective potential for electron–atom interaction, which considers both effects of screening and diffraction in the dense semiclassical plasma, was presented. The way for taking into account of the dynamic screenig was proposed in work [2], where the statical Debye screening radius was replaced by the dynamic one:

$$r_o = r_D(1+\frac{\upsilon^2}{\upsilon_{Th}^2})^{1/2}. \tag{1}$$

Here υ is the relative velocity of the colliding particles, υ_{Th} is the thermal velocity of the particles in the system. Then the effective potential with dynamic screening can be rewritten as [3]:

$$\Phi_{ea}^{dyn}(r) = -\frac{e^2\alpha}{2r^4(1-4\lambda_{ea}^{\;2}/r_o^{\;2})}\left(e^{-Br}(1+Br)-e^{-Ar}(1+Ar)\right)^2, \tag{2}$$

where $A^2 = \frac{1}{2\lambda_{ea}^{\;2}}\left(1+\sqrt{1-4\lambda_{ea}^2/r_o^2}\right)$, $B^2 = \frac{1}{2\lambda_{ea}^{\;2}}\left(1-\sqrt{1-4\lambda_{ea}^2/r_o^2}\right)$.

On the basis of obtained dynamic potential the important characteristics of the collisional processes were investigated, for example, phase shifts, the differential and total scattering cross sections. To determine the phase shifts δ_l of electron-atom scattering in this work the phase-function method was used, where the Calogero equation was solved [4].

References

[1] Ramazanov T.S., Dzhumagulova K.N. and Omarbakiyeva Y.A. Effective polarization interaction potential “charge-atom” for partially ionized dense plasma // Phys.Plasmas. – 2005. – Vol.12.- P.092702

[2] K.N. Dzhumagulova, G.L. Gabdullina, E.O. Shalenov. Dynamic interaction potential and the scattering cross sections of the semiclassical plasma particles // Physics of Plasmas. - 2013. –Vol. 20. – P. 042702.

[3] Dzhumagulova K. N., Shalenov E.O., Ramazanov T. S., Gabdullina G.L. Phase shifts and scattering cross sections of the particles of nonideal semiclassical plasmas based on the dynamic interaction potential // Contr. Plasma Phys. 2014

[4] L.D. Landau and E.M. Lipschitz, “Quantum mechanics (nonrelativistic theory)”, Nauka, Moscow (1989).

P2.17

INVESTIGATION OF EFFECT OF RUNAWAY ELECTRONS IN NONIDEAL PLASMA ON THE BASE OF DYNAMIC INTERACTION POTENTIAL

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Nowadays the investigation of dense plasma’s properties actively develops in connection with the problems of controlled thermonuclear synthesis and tokamaks [1,2]. It should be noted, that the study of the effect of runaway electrons is especially relevant in these systems, because the runaway electrons can be source of some serious instabilities [3,4]. In present work, the friction force acting to electrons was estimated and the conditions of runaway electron (Dreicer field) were derived on the base of dynamic interaction potential [5] of nonideal plasma. It has been shown that for the certain intervals of coupling plasma parameter the differences between the friction force acting on runaway electrons values can be significant for various plasma models.

References

1. B. Esposito, J.R. Martin-Solis. *Phys. Plasmas* 10, 2350 (2003).
2. M. Bakhtiari, D.G. Whyte. *Phys. Plasmas* 13, 112511 (2006);
3. P.B. Parks, Cowan T.E. *Phys. Plasmas* 14, 013102 (2007);
4. T.S. Ramazanov, K.M. Turekhanova. *Phys. Plasmas*. 12, 102502 (2005)
5. K.N.Dzhumagulova, G.L. Gabdullina, E.O.Shalenov. *Phys. Plasmas*. 20, 042702 (2013)

P2.18

Dynamic behavior of polydisperse dust system in cryogenic gas discharge complex plasmas

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Cryogenic complex (dusty) plasma, i.e. dusty plasma in cryogenic discharges, have received increasing interest over the last decade [1-4]. The interest has been largely motivated by extremely low temperature conditions (down to several Kelvins) at those dust structures can exhibit unique structure properties such as very high dust concentration and coupling parameter, formation of compact dust spheres etc.

In this work dust structures consisting of particles of two non-separated fractions forming two-component mixes were obtained in the experiments at 77 and ~10 K. These components differ in both dust ordering and dynamics – some particles are localized in chain-like dust clusters, and some are free-moving particles diffusing trough dust structure with relatively high velocities.

The experiments were conducted in dc glow discharge generated in vertical glass tube placed inside optical helium cryostat. In order to illuminate and register dust structures at cryogenic temperatures the cryostat was supplied with flat round windows. The discharge was generated in helium at pressures of the order of 10^{-2}-10^{-1} Torr and at discharge currents of about 0.1 mA. CeO_2 polydisperse particles of about 3-5 μm in size were injected in plasma from the container positioned above the stratified discharge positive column.

From observation data processing and its analysis particle velocity distribution function were obtained for each dust component. We showed that self-organization of dust in our experiments exhibit kinetic phase transition that aligns velocity of each fast-moving particle in a big ensemble to the average flow direction. Note that two-component dust mixtures were never observed in laboratory experiments before – particles were always separated into fractions according to their size. At cryogenic temperatures we observed the mixtures of polydisperse particles having irregular shape, and formation of two components is more visible at lower temperatures (~10 K). Thus we proposed that formation of such dust mixture is caused by both cryogenic discharge particular features and dust particle shape differences. For example, one component may consist of particles of approximately symmetric shape, another – from strongly asymmetric particles such as elongated rods or discs. In this case the term “binary-like dust system” can be introduced analogously to binary systems in colloids and chemical compositions.

This study was supported by the Russian Science Foundation under Grant No. 14-50-00124.

References

[1] M. Rosenberg, G. J. Kalman *Europhys. Lett.*, 2006, 75, 894.
[2] S.N. Antipov at al *Phys. Plasmas*, 2007, 14, 090701.
[3] W. Sekine, O. Ishihara, M. Rosenberg *J. Plasma Fusion Res. Ser.*, 2009, 8, 290.
[3] S.N. Antipov, M.M. Vasiliev, O.F. Petrov *Contrib. Plasma Phys.*, 2012, 52, 203.
[4] O. Ishihara *Plasma Phys. Control. Fusion*, 2012, 54, 124020.

P2.19

The Dust Particle Dynamics in the Edge Fusion Plasma

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The mechanism of dust production, study of dust-plasma and dust-wall interactions, dust transport, assessment of dust impact on the characteristics of the reactor and safety of fusion devices - all these questions occupy an important place in the study of modern problems of controlled thermonuclear fusion [1-4].

In this paper the transport and the lifetime of the dust particles formed on the surface of the wall of a fusion reactor are considered. The equations of motion, the equations of mass and energy balance describing the dynamics of dust particles were solved. The charge of the dust particle is obtained from the equilibrium condition of zero total current to the dust. The electron and ion charging currents are determined in the approximation of OML theory. The thermionic emission is also taken into account. Accounting for thermionic emission leads to recharging of dust particles, i.e., the potential becomes more positive which in turn leads to a greater dust heating. Therefore thermionic emission can shorten the dust lifetime and path length in the edge fusion plasma.

The calculations for the tungsten dust particle for various fusion plasma parameters are performed. The dust particle charge and energy, depending on the temperature of dust particles are obtained. The temperature and radius of dust particles as a function of time are determined. On the basis of these calculations, estimations of the dust lifetime and the path length in the edge fusion plasma are predicted.

[1]. J. Winter // Physics of Plasmas **7**, 3862 (2000)
[2]. Y. Tanaka, A. Yu. Pigarov, R.D. Smirnov, S.I. Krasheninnikov, N. Ohno and Y. Uesugi // Physics of Plasmas **14**, 052504 (2007)
[3]. R.D. Smirnov, A.Yu. Pigarov, M. Rosenberg, S.I. Krasheninnikov and D.A.Mendis // Plasma Phys. Control. Fusion **49,** 347-371 (2007)
[4]. L. Vignitchouk, P. Tolias and S. Ratynskaia // Plasma Phys. Control. Fusion **56,** 095005 (2014)

P2.20

Ion-Dust and Dust-Dust Scattering Processes in Complex Plasmas

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The aim of the present work is to study the scattering of ions on a spherical dust grain taking into account the dust polarization and the dust-dust scattering process assuming that dust particles can have an induced dipole moment [1]. The absorption of ions and electrons by dust particles and the coagulation of dust grains were not considered.

On the basis of effective screened potentials the influence of the dust particle polarization on classical scattering processes in complex plasmas was studied. Scattering processes for which the polarization effect is unimportant were determined. It has been found that the polarization of the dust grain has a minor effect on the dust-dust scattering in the range $\beta<0.005$, $\beta>0.2$. Zero angle scattering is predicted in the range of the coupling parameter β from 0.005 to 0.2.

For dust charges $Z=10^3$ and 10^2 the coupling parameter $\beta=0.1$ corresponds to dust particle energies E ~172 eV and E ~ 1.72 eV, respectively, where ion temperature is taken equal to T_{ion}=300 K and the condition $T_e \gg T_{ion}$ is taken into account. In gas discharge experiments the kinetic energy of the dust particle has values up to 20 eV [2, 3]. Therefore, for low charged dust particles (Z=100) the prediction of the dust-dust zero angle scattering can be experimentally checked.

References

[1] Giovanni Lapenta, Phys. Scr. **57**, 476 (1998)
[2] Y. A. Ussenov, T. S. Ramazanov, K. N. Dzhumagulova and M. K. Dosbolayev, EPL, **105**, 15002 (2014)
[3] R. A. Quinn and J. Goree, Phys. Plasmas **7**, 10 (2000)
[3] R. A. Quinn and J. Goree, Phys. Plasmas 7, 10 (2000)

P2.21

Spectroscopic diagnostics of Ar/CH_4 and Ar/C_2H_2 complex plasma

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In nowadays there are various well known methods and technologies for production of nanoparticles. Nevertheless, the studies of their growth mechanism and formation in plasma environment are still actual problem. Plasma-chemical processes influence on the plasma optical radiation. Diagnostics of the emission spectrum of the plasma is the one of the methods for investigation the processes occurring in it. Nowadays, methods of the optical diagnostics of plasma have a great development. Spectral diagnostics provides significant information about the parameters of dusty plasma (temperature, concentration of plasma particles) and allows to reach the more detailed understanding of the physical processes in the system, because the advantage of this diagnostics is its non-contact character. In this paper we carried out the study of optical properties of complex plasma in the gas mixture of Ar/CH_4 and Ar/C_2H_2. According to the obtained results of optical diagnostics we found the optimal condition of growth and formation of carbon nanoparticles and nanofilms, and also the effect of the dust component on the spectral characteristics of the buffer plasma. The growth and formation mechanisms were also studied in dependence of percentage of gases in the mixture of Ar/CH_4 and Ar/C_2H_2.

The experimental setup was described in detail in the previous works [1-2]. The working chamber has lateral windows for monitoring the processes in the plasma of RF discharge. The optical system for plasma diagnostics consists of the lens system and spectrometer. The lens system is fixed to provide a clear image of the interelectrodes space on the entrance slit of the spectrometer [3].

Thus, the electron temperature varies for Ar/CH_4 plasma in the range of 1 – 3.0 eV, for Ar/C_2H_2 plasma in the range of 1 – 4 eV at different values of pressure 0.1 – 1 Torr and power 1 – 50 Watt.

References

[1] Ramazanov T.S., Dzhumagulova K.N., Jumabekov A.N., and Dosbolayev M.K., // Phys. Plasmas. – 2008. - №15. – P. 053704.

[2] T. S. Ramazanov, A. N. Jumabekov, S. A. Orazbayev, M. K. Dosbolayev and M. N. Jumagulov // Phys. Plasmas. – 2012. №19. P. 023706.

[3] S. A. Orazbayev, M.M. Muratov, T. S. Ramazanov, M.K. Dosbolayev, M. Silamiya, M. N. Jumagulov, and L. Boufendi The Diagnostics of Dusty Plasma in RF Discharge by Two Different Methods // Contrib. Plasma Phys. – 2013. - V. 53, № 5. - P. 436 – 441.

P2.22

Method of control of ion drag force in dusty plasmas

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In this paper an experimental verification of a method of controlling the ion drag force acting on a dust particle in a complex plasma is present.. This approach is based on the results of calculations of the characteristics of the drift of ions and electrons in the discharge in mixtures of gases with different ionization potentials and the different mass of the ions [1]. If add into a lightweight buffer gas a small fraction of the heavier gas having a lower ionization potential may lead to a radical change in the ionic composition in the gas-discharge plasma [1]. In turn, this causes a significant change in the ion drag force.

The method is realized in experiments with the dusty structures in pure helium and mixtures helium with small additions xenon - up to 5 percent. In this experiment was used an experimental setup that was used in [2]. Dusty plasma created in a mixture of helium and xenon in the discharge tube with a longitudinal magnetic field. Measured the angular velocity of rotation the dust structures in a relatively weak magnetic field (up to 500 gauss), before the rise of inversion of the direction of rotation [2-5]. Measurements were carried out at pressures of 1 and 1.5 Torr in mixtures with the admixture of xenon from 2 to 4 percent (impossible get stable plasma-dust structures in the discharge tube in a magnetic field with large additions of admixture xenon).

Recorded an increase absolute value of the angular velocity of rotation of the structure and the inversion of the direction of rotation occurs at a higher value of magnetic field. The magnitude of the measured angular velocity is consistent with the performance of numerical evaluation of the ion drag force. The increase of angular velocity in a mixture of helium with admixture xenon less than 5 percent, is consistent with the calculation of the characteristics drift of ions and electrons in this mixture [1].

References

[1]. Antipov S.N., Vasiliev M.M., Mayorov S.A., Petrov O.F., Fortov V.E., *JETP*, 2011, 139, p 554.

[2]. Karasev V.Yu., Dzllieva E.S., Ivanov A.Yu., Eichvald A.I., *Phys. Rev. E*, 2006, 74, p 066403

[3]. Vasiliev M.M., Diachkov L.G., Antipov S.N., Petrov O.F., Fortov V.E., *JETP Letters*, 2007, 86, p 414.

[4]. Nedospasov A. V., *Phys. Rev. E,* 2009, 79, p 036401.

[5]. Vasiliev M.M., D'yachkov L.G., Antipov S.N., Huijink R., Petrov O.F., Fortov V.E., *Europhys. Lett.,* 2011, 93, p 15001.

P2.23

Charged Dust Motion in Dust Devils on Earth and Mars

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Charged dust particle dynamics is modeled in the so-called Dust Devils (DDs), which are a widespread event in Earth's and Martian atmospheres. DD is a strong, well-formed, and relatively long-lived whirlwind, ranging from small (half a meter wide and a few meters tall) to large (more than 100 meters wide and more than 1000 meters tall) in Earth's atmosphere. Martian DDs can be up to fifty times as wide and ten times as high as terrestrial dust devils. DDs, even small ones, can produce radio noise and electric fields greater than 10^4 V/m. DD picks up small dust particles. As the particles whirl around, they bump and scrape into each other and become electrically charged. The whirling charged particles also create a magnetic field. The electric fields assist the vortices in lifting materials off the ground and into the atmosphere. Instability characterizing the DD's generation is described by equations analogous to those for internal gravity waves [1]. Mathematically dynamics of DDs is close to that of toroidal plasmas. Correspondingly, methods developed in magnetic fusion research can be used for modeling the DDs. We develop methods for the description of dust particle charging in DDs, discuss the ionization processes in DDs, and model charged dust particle motion. Our conclusions are consistent with the fact that DD can lift a big amount of dust from the surface of a planet into its atmosphere.
This work was supported by the Russian Federation Presidential Program for State Support of Young Scientists (project no. MK-6935.2015.2), the Russian Foundation for Basic Research (project no. 14-05-31410 мол_а), and was carried out as part of the Russian Academy of Sciences Presidium program no. 9 "Experimental and Theoretical Research of Objects of the Solar System and Planetary Systems of Stars".

References

[1] O.G. Onishchenko, W. Horton, O.A. Pokhotelov, L. Stenflo *Physica Scripta*, 2014, 89 (7), 075606.

P2.24

Polarization of Dust Particles surrounded by a Cloud of Trapped Ions in an External Electric Field

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Dust particles immersed into low-temperature low-density plasma acquire a large negative charge. The average charge value of micron-sized dust particles is equal to $eZ_d \sim 10^3$-10^4e depending on the plasma conditions (electron and ion temperature, the kind of neutral atoms and their density, and the particle radius). In plasma, dust particles are surrounded and screened by ion clouds, which consist of trapped and free ions [1-3]. The trapped ions form a positive shell of so-called "dust quasi-atoms", which can be polarized by an external electric field.

The paper considers the polarization of dust quasi-atoms in the external electric field with the help of Monte Carlo simulation of ions movement and their charge exchange collisions with neutral atoms. Monte Carlo simulation makes it possible to obtain the ion density distribution around a particle. It is shown that in the external electric field the ion cloud around the dust particle becomes asymmetric, i.e. it is polarized and acquires a very large dipole moment; see [3-4]. It is found out that for small reduced electric fields $\overline{E} = eE_z l_i / kT_i) < 1$ the dipole moment of a dust quasi-atom is proportional to the reduced electric field ($l_i = 1/N_g \sigma_{\rm res}$ is the mean free path length of ions in the parent gas with N_g density). The coefficient of polarizability $\alpha(E)$ is independent of the reduced electric charge of the dust particle $Q=eZ_d/\lambda_i kT_i$ and proportional to the cube of ion Debye length, $\lambda_i=(kT_i/4\pi e^2 n_0)^{1/2}$, i.e. $\alpha(\overline{E} \to 0) \approx A(l_i)\lambda_i^3$. For $l_i>\lambda_i$, the coefficient of proportionality $A(l_i)$ depends on the mean free path length of ions l_i *as* $A(l_i) \approx 0.5 l_i / \lambda_i /(1 + l_i / 25\lambda_i)$. However, the coefficient of polarizability decreases with the decrease of the ion mean free path length for $l_i<\lambda_i$. For $\overline{E} \ge 1$, the coefficient $\alpha(\overline{E})$ begins to decrease with the increase of a reduced electric field, $\alpha(\overline{E}) \sim \overline{E}^{-\beta}$ with $\beta \approx$ 0.5-0.66. The decrease of the coefficient of polarizability $\alpha(\overline{E})$ is connected with the field ionization of "dust quasi-atoms" [3].

The induced dipole moment of "dust quasi-atoms" influences inter-particles interaction and can be responsible for the formation of dust structures in complex plasmas.

References

[1] M. Lampe, et. al., Phys. Plasmas 2003, **10** (5), pp.1500-1513.
[2] A.V. Zobnin, et. al., Phys. Plasmas 2008, **15**, pp. 043705(6).
[3] G.I. Sukhinin, A.V. Fedoseev IEEE Trans. on Plasma Science., 2010, **38** (9), pp. 2345-2552.
[4] G.I. Sukhinin, A.V. Fedoseev, R.O. Khokhlov, and S.Yu. Suslov Contrib. Plasma Phys., 2012, **52** (1), pp. 62-65.

P2.25

Global orientational order parameter in the two-dimensional Yukawa systems

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Structural properties of non-ideal matter are determined by its phase state and conditions of phase transitions. Studies in this connection are of great interest both from fundamental and practical points of view in various fields of physics [1-4]. Special attention is given to the investigations of two-dimensional (*2d*-) systems, which have found their commercial application in the area of micro- and nano- technologies, as well as in development of new materials and special coatings with specified properties [3, 4]. One of the reasons for this fact is the possibility of direct experimental verification of existing analytical and numerical results, for example, in experiments with monolayer dust structures in plasma of radio frequency capacitive discharge.

Melting processes in monolayer dusty plasma structures are typically studied by the analysis of the shape of pair and bond-angular correlation functions, which has strict limitations on the number of observed particles and the degree of uniformity of the studied systems. Often in laboratory experiments with dusty plasma, the formation of various irregularities, in particular the so-called domains, is observed, which can significantly affect the melting process in the two-dimensional non-ideal structures. In this regard, the study of global order parameters (translational and orientational) seems promising, since these parameters will vary appreciably even in the real experiments with dusty plasma structures with different structural pertubations, and they can be used not only for extended monolayer structures, but also for systems with a small number of particles.

In our work we present the results of a numerical study of the global orientational order parameter as a function of coupling parameter of two-dimensional system, as well as of the number of particles in the small size (cluster) systems. The calculations were performed for non-ideal two-dimensional system of particles interacting via Yukawa potential in a wide range of parameters corresponding to the experimental conditions in the laboratory dusty plasmas.

References

[1] N.H. March, M.P. Tosi, *Introduction to Liquid State Physics*, World Scientific, (1995).

[2] B. Pullman, *Intermolecular Interactions: From Diatomics to Biopolymers,* Wiley Interscience, Chichester (1978).

[3] V.E. Fortov and G.E. Morfill, *Complex and Dusty Plasmas*, CRC Press (2010).

[4] Ivlev A, Morfill G, Lowen H and Royall C.P. Complex Plasmas and Colloidal Dispersions: Particle-Resolved Studies of Classical Liquids and Solids, World Scientific (2012).

15th International Conference on the Physics of Non-Ideal Plasmas
31 August – 4 September 2015
Almaty, Kazakhstan

PNP

Abstracts of talks

Friday 04.09.2015, 9:00 – 12:30

I8: Friday 04.09.2015, 9:00 - 9:40

Non-ideal plasmas in Extreme, Relativistic Fields

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When an ultrahigh intensity laser interacts with matter at intensities $>10^{20}$ W/cm^2 and on timescales of fs, the matter instantaneously turns into a non-ideal plasma far from equilibrium. At the Center for High Energy Density Physics at the University of Texas at Austin, the Extreme Fields and Relativistic Plasmas group, studies this fundamental interaction of extreme laser fields with plasmas. A main regime of interest is that of relativistic transparent plasmas. Here, a classically overdense plasma is turned transparent by relativistic effects on a timescale of just a few laser cycles. Such a relativistic transparent plasma has been shown to be a very efficient source of high energy electrons and ions, accelerating protons to >150 MeV proton energies and carbon ions to >1 GeV, twice what is required e.g. for fast ignition of fusion targets. Exploiting these relativistic plasma mechanisms we were also able to demonstrate the highest flux per Joule and brightest laser-driven neutron sources with $>10^{10}$ neutrons/shot @ 60J pulse energy at Trident and an ultrashort neutron source with $>10^{18}$ neutrons/s at the Texas PW. These plasmas are also a source of coherent synchrotron emission, emitting high brilliance coherent x-rays at keV energies.

For even higher intensities, simulations predict the plasma to be dominated by radiation and ultimately quantum effects. To describe the behavior of a charged particle in these extreme electromagnetic fields, perturbative semi-classical models and effective nonlinear quantum field theories have to be employed. These models are as of yet untested by experiments. To reach these new regimes of physics we are currently upgrading the Texas-PW laser with the goal to achieve on-target laser intensities of up to $5x10^{22}$ W/cm^2 at ultrahigh contrast. I will report on recent progress as well as on planned experiments in the radiation dominated and QED regimes.

T46: Friday 04.09.2015, 9:40 - 10:00

Negative pion stopping and mesomolecules formation in ultradense plasmas of ICF/WDM concern

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Elaborating in the fast ignition scenario(FIS) for inertial confinement fusion (ICF) on the possibilities of negative pion production with ultra-relativistic electron beams in the hundred MeV energy range[1] out of deuteron or triton electrodisintegration we consider the stopping and range of the produced negative pion in a dielectric framework supplemented with multiple scattering corrections[2].The production of exo-atoms with D+ or T+ ions near the end of range is estimated for thermalized pions while including direct hadronic interactions with the corresponding nuclei. Further interactions of these exo-atoms with surrounding D+ or T+ ions are shown lead to toexo-hydrogenic molecular ions through the exo-atoms polarizability and electric dipole moment. Subsequent deexcitation of these exo-molecular ions is then demonstrated to promote direct nuclear fusion between the two nuclei. This novel catalysis fusion scheme take also advantage of the very dense plasmas surrounding the reacting nuclei which could feature a much swifter process contrasted to the usual catalysis in cold hydrogen.

References

[1] C. Deutsch and J.P. Didelez, LaserPart. Beams 29, 39 (2011).
[2] C. Deutsch and P. Fromy, J.Plasma Phys 79, 391 (2013).

T47: Friday 04.09.2015,10:00 - 10:20

Continual-Atomistic Simulation of the Behaviour of Metal under the Action of Double Femtosecond Laser Pulses

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An interaction of femtosecond laser pulses with metal is simulated in this work and the attendant phenomena (such as ablation, nucleation, nanoparticles and nanoclusters formation, shock waves origination and propagation in the target) are investigated using the method of the numerical simulation. An improved version of the combined continual-atomistic model [1] is used for simulation, this model is based on the molecular-dynamics simulation for ions and on the heat conduction equation solution for electrons. Our version of this model takes into account laser absorption according to Helmholtz equation as well as dependencies of electron thermal conductivity and electron-ion coupling on density and temperature [2]. The Thomas–Fermi model is used for describing the electronic heat capacity, the inter-ions interaction is defined using inter-particle EAM-potential.

This combined model represents the dynamics of laser ablation, melting, evaporation, ionization, nucleation, shock and rarefaction wave propagation more accurately (corresponding with the model [3]), as well as nanoparticles formation, especially under the action of double laser pulse, because of the first pulse changes the substance properties. In this work, we simulate the laser ablation of aluminum under the action of 100 fs double laser pulse (0-200 ps between single pulses) with fluence up to 2 J/cm^2 and we find out the ablation crater depth as a function of the delay between pulses. Our results of modeling are in the good agreement with the experimental data.

References

[1] Ivanov D.S., Zhigilei L.V. Combined atomistic-continuum modeling of short-pulse laser melting and disintegration of metal films // *Phys. Rev. B.* (2003). V. 68. P. 064114.
[2] Povarnitsyn M.E., [et al] // *Appl. Surf. Sci.* (2012). V. 258. P. 9480.
[3] Povarnitsyn M.E., Itina T.E., Sentis M., Khishchenko K.V., Levashov P.R. Material decomposition mechanisms in femtosecond laser interactions with metals // *Phys. Rev. B.* (2007). V. 75. P. 235414.

T48: Friday 04.09.2015,10:20 - 10:40

Dynamical screening and wake effects in classical, quantum, and ultrarelativistic plasmas

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Wakefields are of omnipresent nature in non-equilibrium situations, but their appearance and parametrical scaling is very diverse. Therefore, the topological structure and characteristics of the dynamically screened potential is outlined for three representative systems in completely different physical regimes: (i) a classical complex (dusty) plasma [1], (ii) a degenerate electron-ion plasma at high densities [2], and (iii) an ultrarelativistic quark-gluon plasma [3]. For the efficient high resolution computation of the 3D plasma potentials, the recently developed linear-response code *Kielstream* is used [4]. It is found that the wakefield of a charged particle is most pronounced in a classical gas discharge plasma. The considered non-classical plasmas share several features with respect to the topology of their wake field and its parametrical scaling. Anomalous, collision-induced wake amplification is reported for all three systems [5]. For classical plasmas, we present improved wakefields that take into account the non-Maxwellian character of the ion distribution.

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References

[1] Ludwig *et al.*, New J. Phys. **14**, 053016 (2012)
[2] Moldabekov *et al.*, PRE **91**, 023102 (2015)
[3] Chakraborty *et al.*, Phys. Rev. D **74**, 094002 (2006)
[4] Ludwig *et al.*, In: Springer Series on Atomic, Optical and Plas. Phys. **59**, 73 (2014)
[5] Moldabekov et al. Contrib. Plas. Phys. **55**, 186 (2015)

I9: Friday 04.09.2015,11:10 - 11:50

Charging of polarizable dust particles in the orbital motion limited approximation

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Dusty plasmas are formed when micron-sized particles, called grains, are suspended in a plasma consisting of electrons and ions. It is well known that under ordinary experimental conditions micron-sized particles readily acquire high negative electric charge that ranges from dozens to thousands of the elementary. This immediately results in that the grains turn a strongly correlated system in which the average interaction potential energy is usually orders of magnitude higher than the thermal kinetic energy. It is rather obvious that all physically meaningful properties of the dust component are strictly governed by the intergrain interaction energy, which is, to a large extent, is determined by the grain charge.

When a dust particle is immersed into an ambient plasma, it starts to absorb electrons at a much higher rate than ions since the corresponding fluxes on the grain surface are determined by a mobility which is mass dependent. Gradually charging the dust particle begins to repel the electrons and attract the ions that eventually makes the total electric charge flux on the grain surface vanish. This condition is widely used to calculate the grain charge, for example, within the so-called orbit motion limited (OML) approximation [1].

The standard version of OML assumes that the interaction between the electrons and ions on the one hand and the dust particle on the other is purely Coulombic. It is proposed herein to take into account the polarization effects which is particularly implemented by invoking the charge image method [2]. The polarization phenomena significantly modify the standard OML calculation and numerical evaluations show that the electrostatic induction plays an essential role, especially when the charge of dust particles is not too high. In addition the obtained results asymptotically approach those data of the OML with the pure Coulomb interaction potential when the grain charge grows.

The present investigation, together with the results of [3], opens up a new ground for constructing a self-consistent theory of the static properties of the dust component that regularly treats the finite size of the dust particles and the polarization phenomena.

References

[1] V. N. Tsytovich, Phys. Usp., 1997, 40, pp 53–94
[2] V. A. Saranin, Phys. Usp., 1999, 42, pp 385–390
[3] L T. Erimbetova, A. E. Davletov, Zh. A. Kudyshev, Ye. S. Mukhametkarimov, Contrib. Plasma Phys. 2013, 53, pp 414–418

T49: Friday 04.09.2015,11:50 - 12:10

Dust and Dusty Plasmas at the Moon: Recent Research and Future Lunar Missions

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From the Apollo era of exploration, it was discovered that sunlight was scattered at the terminators giving rise to "horizon glow" and "streamers" above the lunar surface. Subsequent investigations have shown that the sunlight was most likely scattered by electrostatically charged dust grains originating from the surface. A renaissance is being observed currently in investigations of the Moon. The Luna 25 and Luna 27 missions are being prepared in Russia. These missions will include investigations of lunar dust and dusty plasmas at the Moon. Here we discuss the future experimental investigations related to dust and dusty plasmas within the missions of Luna 25 and Luna 27.

Lunar dust over the Moon is usually considered as a part of a dusty plasma system. We present the main our theory results concerning the lunar dusty plasmas. We start with the description of the observational data on dust particles on and over the surface of the Moon. We show that the size distribution of dust on the lunar surface is in a good agreement with the Kolmogorov distribution, which is the size distribution of particles in the case of multiple crushing. We consider the processes influencing the dust particle rise over the lunar surface. We discuss the role of adhesion which has been identified as a significant force in the dust particle launching process. We evaluate the adhesive force for lunar dust particles with taking into account the roughness and adsorbed molecular layers. We show that dust particle launching can be explained if the dust particles rise at a height of about dozens of nanometers owing to some processes. This is enough for the particles to acquire charges sufficient for the dominance of the electrostatic force over the gravitational and adhesive forces. The reasons for the separation of the dust particles from the surface of the Moon are, in particular, their heating by solar radiation and cooling. We consider migration of free protons in regolith from the viewpoint of the photoemission properties of the lunar soil.

Finally, we develop a model of dusty plasma system over the Moon and show that it includes charged dust, photoelectrons, and electrons and ions of the solar wind. We determine the distributions of the photoelectrons and find the characteristics of the dust which rise over the lunar regolith. We show that there are no significant constraints on the Moon landing sites for future lunar missions that will study dusty plasmas in the surface layer of the Moon. We discuss also waves in dusty plasmas over the lunar surface. Furthermore, we formulate new problems concerning the dusty plasma over the lunar surface.

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T50: Friday 04.09.2015,12:10 - 12:30

Formation of Coulomb structures in a magnetic trap under cryogenic temperatures

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Strongly coupled Coulomb systems are of considerable fundamental and applied interest. In recent years, dusty plasma structures are frequently considered as a macroscopic physical model of Coulomb systems which can visually be observed. However, charged dust particles in plasma are screened, and the potential of interparticle interaction becomes a Yukawa (Debye) one. Besides, in dusty plasmas, the charge of the dust particles is responsible both for interaction with other particles (and consequently for the formation of a cluster or structure) and for its levitation in electrical fields (of RF or DC discharges). So, changing the interparticle potential, one changes the levitation conditions.

The way for formation of macroscopic Coulomb systems is levitation of a Coulomb cluster of charged diamagnetic particles in nonuniform magnetic fields [1,2]. In this case the levitation conditions are independent on the particle charge and depend on the magnetic susceptibility of the particle matter.

In this work we consider the possibility of the stable levitation of Coulomb structures of charged superconducting macroparticles (which are ideal diamagnetic) in static magnetic traps at cryogenic temperatures. The results of formation of the strongly coupled structures of 10^3 particles in a magnetic field are presented. Ordered structures were formed by particles 30-60 μm in size of charge $4 \cdot 10^6$e. Charges on the particles were varied in sign and could be both positive and negative. On a base of experimental data we obtained a mean interparticle distance, which is 200 μm. Estimates of coupling parameter of dusty system amounted to $\sim 10^5$.

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References

[1] Savin S.F., D'yachkov L.G., Vasiliev M.M. et al., *EPL*, 2009, V.88 (6), p.64002.
[2] Petrov O.F., Myasnikov M.I., D'yachkov L.G. et al., *Phys. Rev. E*, 2012, V.86, p. 036404.

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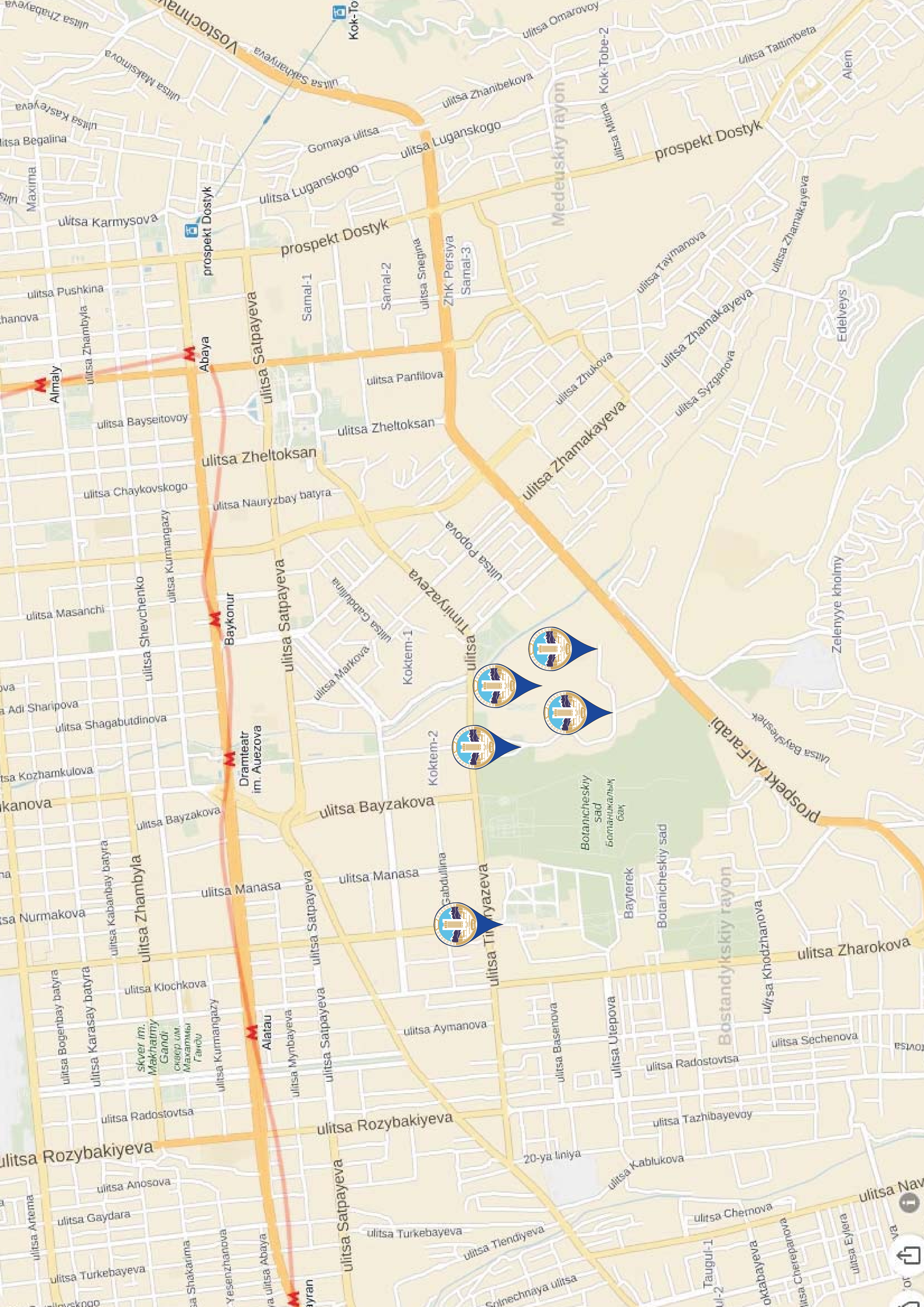
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PNP-15 Program

Almaty, August 30 – September 4, 2015

The Best Western Plus Atakent Park Hotel, Timiryazev Street 42, 050057 Almaty

Time-Table	Sun. Aug. 30	Mon. Aug. 31	Tue. Sep. 1	Wed. Sep. 2	Thu. Sep. 3	Fri. Sep. 4	Time-Table
8:30	Arrival	Opening					
9:00		I1 Bonitz	I3 R. Magyar	I5 Tkachenko	I6 Nettelmann	I8 Hegelich	9:00
9:40		T1 Redmer	T13 Sengebusch	T26 Reinholz	T33 Hoffmann	T46 Deutsch	9:40
10:00		T2 Silvestri	T14 Dubovtsev	T27 Kang	T34 E. Son	T47 Fokin	10:00
10:20		T3 V. Filinov	T15 Khrapak	T28 A. Filinov	T35 Zhao	T48 Ludwig	10:20
10:40-11:10		Coffee Break					10:40-11:10
11:10		T4 Maiorov	T16 Filatova	T29 Bystryi	T36 Dyachkov	I9 Davletov	11:10
11:30		T5 Inerbaev	T17 Rosmej	T30 Ott	T37 Sukhinin	T49 Popel	11:50
11:50		T6 Somsikov	T18 Cebulla	T31 Apfelbaum	T38 Kaehlert	T50 Vasiliev	12:10
12:10		T7 Moldabekov	T19 Ussenov	T32 Hou	T39 Pal	Closing	12:30
12:30 - 14:00		Lunch & Discussions					13:00
14:00		I2 Fortov	I4 Iosilevskiy	Social Event and Excursion	I7 Petrov	Departure	
14:40		T8 Mintsev	T20 Schöttler		T40 Hartmann		
15:00		T9 Telekh	T21 Groth		T41 Filippov		
15:20		T10 Dornheim	T22 Kunakov		T42 Koss		
15:40-16:10	Registration (The Best Western Plus Atakent Park Hotel)	Coffee Break			Coffee Break		
16:10		T11 Karasev	T23 Gryaznov		T43 Vasilyak		
16:30		T12 Fedoseev	T24 Ismagambetova		T44 Valuev		
16:50		In remembrance of academician **Fazylkhan Baimbetov** (Ebeling, Fortov, Deutsch)	T25 Martynova		T45 Dzhumagulova		
17:10			Poster Session I		Poster Session II		
17:30							
17:50		Free Time					
18:30							
19:10							
19:30	Welcome reception (The Best Western Plus Atakent Park Hotel)		Free Time	Free time	Conference Dinner		
20:30							
21:00	Free Time						
21:30							

All sessions are held in conference hall of the Best Western Plus Atakent Park Hotel.
9 Invited Talks (I): 40 minutes, 50 Topical Talks (T): 20 minutes including discussions
Poster sessions are held in the Best Western Plus Atakent Park Hotel
The PNP business meeting (Programm Committee) is scheduled on Tue. Sep. 1 during the lunch break
Lunches and coffee will be served in the Best Western Plus Atakent Park Hotel (free for all participants)
WLAN is available in The Best Western Plus Atakent Park Hotel during the conference (free for all participants)

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National Laboratory of Nanotechnology
TNS-INTEC
Institute of Applied Sciences and Information Technologies
IASIT
Laboratory of Engineering Profile