INTERNATIONAL CONFERENCE

Strongly Coupled Coulomb Systems (SCCS2008)

29 July - 2 August 2008, Camerino, Italy

Program Committee:

James Dufty (chair)
Michael Bonitz
Gilles Chabrier
Vladimir Filinov
Gabor Kalman
Michael Murillo
David Neilson
Gaetano Senatore

Organising Committee:

David Neilson (co-chair)
Gaetano Senatore (co-chair)
Stefania De Palo
Vittorio Pellegrini
Andrea Perali
Pierbiagio Pieri

Sponsors

University of Camerino

ICAM – I2CAM

International Centre for Theoretical Physics

DEMOCRITOS INFM

National Enterprise for nanoScience & nanoTechnology

National Science Foundation

Physical Sciences Laboratory
Univ. Wisconsin-Madison

Astrophysics, Dense hydrogen and helium, and Quark-gluon plasmas

Pierleoni Carlo
High pressure hydrogen: new predictions by CoupledElectron-Ion Monte Carlo

Carlo Pierleoni
Department of Physics, University of L'Aquila, Italy

The physical behaviour of hydrogen under megabar compression is still largely unknown because experimental difficulties prevent a systematic investigation of the phase diagram in the interesting range of pressures and temperatures. Ab-initio theoretical methods have been exploited to interpret the scattered experimental data and to make predictions. However the problem is particularly diffcult because the energy scales of several different phenomena, such as electronic correlations, protonic quantum effects, finite size effects in the metallic phase and in the metal-insulator transition region, becomes comparable and need to be considered together in a non perturbative manner. Quantum Monte Carlo methods are unique in their ability to treat all those effects with high accuracy in simple systems. In recent years we have developed a new QMC method, the Coupled Electron-Ion Monte Carlo (CEIMC) [1], which is particularly suitable to study hydrogen under high pressure. After a brief introduction to the physics of high pressure hydrogen, I will describe the main ingredients of the new method and present results from CEIMC. In particular I will discuss the metallic phase of hydrogen at pressures beyond the molecular dissociation threshold, including the melting of the proton crystal [2], and the molecular dissociation phenomena in the liquid phase [3].

[1] C. Pierleoni and D. M. Ceperley, Lecture Notes in Physics vol 741 pp 641-683 (2006), xxx.lanl.gov/abs/physics/0510254. [2] C. Pierleoni, D.M. Ceperley and M. Holzmann, Phys. Rev. Lett. 93, 146402 (2004). [3] K. Delaney, C. Pierleoni and D.M. Ceperley, Phys. Rev. Lett. 97, 235702 (2006).

Militzer Burkhard
Jupiter's Mantle and Core Characterized by First-Principles Simulations

Burkhard Militzer
Departments of Earth and Planetary Science and Astronomy, University of California, Berkeley, CA 94720, USA

Most of the over two hundred discovered extrasolar planets are gas giants that are primarily composed of dense fluid hydrogen and helium at megabar pressures and temperature of thousands of degrees Kelvin. The characterization of hydrogen-helium mixtures at such extreme conditions has posed a challenge to experimental and theoretical methods [1] but significant progress has been made with recent shock wave experiments. The combination of static and dynamic compression techniques allowed one probe deeper into planetary interiors. Here we compare theoretical [2] and experimental [3] results for shock-compressed helium. By combining path integral Monte Carlo and density functional molecular dynamics simulations, an equation of state for hot, dense helium is obtained.
The main topic of this presentation will be a new model for Jupiter's interior that was derived from an extensive set of density-functional molecular dynamics simulations [4]. The presented model revises our understanding of Jupiter's interior structure. A characterization of Jupiter's core and mantle will be given and implications for its formation mechanism will be discussed. The properties of the molecular-to-metallic transition in hydrogen [5] will be related to the convection in Jupiter's mantle.
Furthermore, the mixing properties of hydrogen and helium will be examined with first-principles simulations at high pressure. We revisit the demixing hypothesis put forward by Stevenson and Salpeter [6] in order to explain the unusually slow cooling rate of Saturn. The mixing properties will be explained in terms of structural and electronic properties of the two fluids.

[1] B. Militzer, W. B. Hubbard, Proceedings, American Physical Society meeting on Shock Compression of Condensed Matter, Hawaii, June, 2007.
[2] B. Militzer, Phys. Rev. Lett. 97, 175501 (2006).
[3] J. Eggert et al., Phys. Rev. Lett. 100, 124503 (2008).
[4] J. Vorberger et al., Phys. Rev. B 75, 024206 (2006).
[5] J. Vorberger et al., Contrib. Plasma Phys. 47, 375 (2007).
[6] D. J Stevenson, E. E. Salpeter, Astrophys. J. Suppl., 35, 239 (1977).

Filinov Vladimir
Thermodynamic properties and electrical conductivity of stronglycorrelated plasma media

V.S. Filinov(1), M. Bonitz(2), H. Fehske (3), M., V.E. Fortov(1), P. Levashov(1)
(1)Joint Institute for High Temperatures RAS, Moscow, Russia (2)Universitat zu Kiel, Kiel, Germany (3)Universitat zu Greifswald, Greifswald, Germany

We present results for 3D hydrogen and 2D e-h plasmas in a wide region of temperature, density and electron to hole mass ratio. Our calculations include region of appearance and decay of the bound state, Mott transition from neutral plasma to metallic-like clusters, formation from clusters the hexatic-like liquid and then formation of the crystal-like lattice and at very low temperatures transition of this latice to antiferromagnetic structure. In our studies we use the direct quantum path integral Monte Carlo method developed in our previous works for studying strongly correlated two component plasma media at finite temperature. Internal energy, pressure and pair correlation functions have been obtained in wide range of density and temperatures.
Combining both molecular dynamics and Monte Carlo methods for solving the integral Wigner - Liouville equation we have calculated the temporal momentum-momentum correlation functions and their frequency-domain Fourier transforms. In a canonical ensemble at finite temperature for weakly coupled plasmas obtained numerical results agree well with Drude approximation and Silin, Rukhadze formula. Growth of coupling parameter results in strong deviation the frequency dependent conductivity and permittivity from low density and high temperature approximations.
Applications of the developed approach is possible to treatment other dense plasma media such as electrons in metals and so on.

Heinz Ulrich
The strongly coupled quark-gluon plasma created at RHIC

Ulrich Heinz
The Ohio State University Physics Department 191 West Woodruff Avenue Columbus, OH 43210-1117 USA

The Relativistic Heavy Ion Collider (RHIC) was built to re-create and study in the laboratory the extremely hot and dense matter that filled our entire universe during its first few microseconds. Its operation since June 2000 has been extremely successful, and the four large RHIC experiments have produced an impressive body of data which indeed provide compelling evidence for the formation of thermally equilibrated matter at unprecedented temperatures and energy densities – a "quark-gluon plasma (QGP)". A surprise has been the discovery that this plasma behaves like an almost perfect fluid, with extremely low viscosity. Theorists had expected a weakly interacting gas of quarks and gluons, but instead we seem to have created a strongly coupled plasma liquid. The experimental evidence strongly relies on a feature called "elliptic flow" in off-central collisions, with additional support from other observations. I will explain how we probe the strongly coupled QGP, describe the ideas and measurements which led to the conclusion that the QGP is an almost perfect liquid, and show how they tie relativistic heavy-ion physics into other burgeoning fields of modern physics, such as strongly coupled Coulomb plasmas, ultracold systems of trapped atoms, and superstring theory.

Thoma Markus

What can we learn from electromagnetic plasmas about the quark-gluon plasma?

Markus H. Thoma
Max-Planck-Institute for Extraterrestrial Physics, P.O. Box 1312, 85741 Garching, Germany

Ultra-relativistic electromagnetic plasmas can be used for improving our understanding of the quark-gluon plasma [1]. In the weakly coupled regime both plasmas can be described by transport theoretical and quantum field theoretical methods leading to similar results for the plasma properties (dielectric tensor, dispersion relations, plasma frequency, Debye screening, transport coefficients, damping and particle production rates). In particular, future experiments with ultra-relativistic electron-positron plasmas in ultra-strong laser fields might open the possibility to test these predictions, e.g. the existence of a new fermionic plasma wave (plasmino). In the strongly coupled regime electromagnetic plasmas such as complex plasmas can be used as models or at least analogies for the quark-gluon plasma possibly produced in relativistic heavy-ion experiments. For example, pair correlation functions can be used to investigate the equation of state and cross section enhancement for parton scattering can be explained.

[1] S. Mrowczynski and M.H. Thoma, Ann. Rev. Part. Sci. 57 (2007) 61.

Astrophysics, Dense hydrogen and helium, and Quark-gluon plasmas - Posters

Brown Lowell S.
Charged Particle Motion in a Plasma: Electron-Ion Energy Partition

Lowell S. Brown, Dean L. Preston, and Robert L. Singleton Jr.
Los Alamos National Laboratory Los Alamos, New Mexico 87545, USA

Fast charged particles traversing a plasma deposit energy loss dE/dx to both the electrons and the ions in the plasma. We compute the energy partition, the fractions of the total energies deposited to the electrons E_e and to the ions E_I, E_e/E_0 and E_I/E_0, when charged particles of initial energy E_0 slow down to come into an equilibrium distribution. This we do for weak to moderately coupled plasmas to leading and first subleading order in the dimensionless plasma coupling constant which translates to computing to the order $n \ln n$ and n in the plasma density n. This is done in an unambiguous way using a well-defined Fokker-Planck equation [1]. The precise results take account of the thermalization of the fast particles and involve detailed integrals over weight functions A_I and A_e that appear in the Fokker-Planck equation and not simply the ion and electron stopping powers dE_I/dx and dE_e/dx. The case in which the ions and electrons in the plasma have different temperatures is of particular interest. Here the fast particles end up in a non-thermal equilibrium distribution that works to bring the ions and electrons in the plasma back into thermal equilibrium.

[1] L. S. Brown, D. L. Preston, and R. L. Singleton, Jr., Phys. Rep. 410, 237 (2005) .

Demura Alexander
"Averaged" Diffusion of Radiation in Spectral Lines

A.V. Demura, G.V. Demchenko
HEPTI, RRC "Kurchatov institute", Kurchatov Square 1, Moscow 123182, Russia

The modeling of gas divertors for ITER and other tokamak devices requests to perform large scale computations of atomic kinetics with radiation transfer for rather high density, nonuniform and nonequilibrium peripheral interjacent plasma - gas layer [1]. In these systems the influence of radiation transfer on plasma equilibrium and atomic kinetics is quite essential, and thus its correct description plays significant role although represents itself quite a complicated task. In these conditions the spectral lines of the main species are severely trapped due to the surrounding plasma peripheral layer of relatively dense neutral gas [1]. In this work we present a model of "averaged" diffusion of radiation in spectral lines applied for the approximate description of radiation transfer in [1] that enables to decrease substantially computer time consumption and at the same time to preserve affordable accuracy for such type of problems with important role of the radiation transfer processes. In this model the essential spectral interval of each line is divided into two regions of strong and weak absorption (compare with [2]). The latter region corresponds to the wings, where photons easily escape the medium [2]. So, in the case of strongly trapped spectral lines we reduce the radiation transfer equations in the center to the diffusion-like equations and introduce the "effective photons" by averaging over frequency [1]. Thus the present model of "averaged" radiation diffusion describes the radiation transfer in terms of the "effective photons". The description of radiation transfer in the line wings, where formally the diffusion-like equations are not valid, in fact could be achieved in the frames of the same equations by introduction of corresponding sink terms [1], that could be evidently expressed through escape factors.

[1]. N.V. Antonov, A.V. Demura, G.V. Demchenko, V.B. Petrov, B.I. Khripunov, G.V. Sholin, Kinetics of Atomic Excited States Population with Account of Resonance Radiation Transfer in Interajacent Region Plasma-Gas, Preprint IAE-6409/6, RRC "Kurchatov institute", Moscow, 2006, 1–46 (in Russian).
[2]. V. A. Abramov, V.I. Kogan, V.S. Lisitsa, Radiation Transfer in Plasma, in Plasma Theory Reviews v. 12, ed. M.A. Leontovich, B.B. Kadomtsev, Moscow, Energoizdat, 1982, pp. 114–155 (in Russian).

Däppen Werner
The role of the quality of the equation of state in solar and stellar modeling

Werner Däppen
Department of Physics and Astronomy University of Southern California Los Angeles, CA 90089-1342 U.S.A.

The modulation of the equation of state by the chemical composition leads to a natural method to determine the helium and heavy-element abundance in the Sun and in stars. For the helium in the Sun, this has grown into the only reliable method. Its result (0.24-0.25 in mass fraction) has turned out to be substantial lower than the values inferred from solar modeling (0.27-0.28), a discrepancy which drew renewed attention to the importance of the effect of gravitational settling during solar evolution. By its very nature, the result of this method is only as good as the quality of the underlying equation of state, for which so far there are only theoretical formalisms, but no laboratory experiments. However, careful astrophysical observations allow us to put constraints on the quality of the equation of state. A relentless effort to improve the equation of state is therefore desirable. Both phenomenolgical and rigorous approaches can be pursued. As an example of the phenomenological efforts, I discuss a recent parameterization of a free-energy-minimization method. I also report on the implementation of rigorous virial expansions. Despite their limited domain of applicability to only parts of the stellar interior, there are considerable prospect for an observational diagnosis, both in solar and stellar seismology.

Ebeling Werner
Enhancement of fusion in strongly coupled plasmas -revisited

Werner Ebeling (1), Mike Yu. Romanovsky (2)
(1) Institute of Physics, Humboldt University Berlin Newtonstr. 15, D-12489 Berlin
(2) General Physics Institute, Academy of Science, Vavilova 38, R-119991 Moscow

The fusion of light nuclei is the source of the radiation of the sun and the stars and might be the only final solution of the energy problem of mankind. Since the pioneering work of Schatzman (1948) the relevance of dense plasma effects have been discussed by many experts in the field as Jancovici, De Witt, Ichimaru and others. In view of the relevance of the problem we will take up the problem again and discuss several enhancement effects including equilibrium and nonequilibrium correlations. In particlular we will discuss the influence of plasma microfields under conditions of nonideality and nonequilibrium, including finite size effects. On the basis of the general statistical theory of fusion processes we study the influenece of different factors on the relative velocity and acceleration in reacting collisions of nuclei, including Kepler-type motions, finite-size effects and the influence of multiply-charged ions. In particular we study the influence of nonequilibrium effects and the role of mean fields, mesoscopic and microscopic fields in infinite systems and in finite clusters including effects connected with the Coulomb explosion of clusters. The role of short-time nonequilibrium distributions of the velocity and the fields including long tails is discussed and estimated.

Ref: M.Yu. Romanovsky and W. Ebeling, Physica A. 252 488 (1998), Laser Physics 14, 850 (2004) Contrib. Plasma Phys. 46 195 (2006).

Filinov Alexey
Melting of Trapped Few-Particle Systems

J.Boening(1), A.Filinov(1,2), P.Ludwig(1), H.Baumgartner(1), M.Bonitz(1) and Yu.E.Lozovik(2)
(1) Institut fuer Theoretische Physik und Astrophysik, University Kiel, D-24098 Kiel, Germany (2) Institute of Spectroscopy of the Russian Academy of Sciences, 142090 Troitsk, Russia

Crystallization and melting and, more generally, phase transitions are well known to pertain to very large systems only. At the same time, solid-like or liquid-like behavior has been observed in finite systems containing only one hundred or even 10 particles [1].
A particularly simple and transparent quantity to detect melting is the magnitude of the particle position fluctuations normalized to the interparticle distance known as Lindemann ratio u_L. A modified definition which works also for 2D systems is the *relative interparticle distance fluctuations* (IDF) [2,3] $u_r = \frac{2}{N(N-1)} \sum_{1\le i<j\le N} \frac{\langle r_{ij}^2\rangle}{\langle r_{ij}\rangle^2} - 1$ (1). For finite systems however, the results for u_r and the melting point depend crucially on the method of calculation and on its duration. Increasing the length of a computer simulation (and the expected accuracy) may lead to growing systematic errors predicting a too low melting temperature [4,5].
We investigate the cause of this fundamental problem and propose a simple solution. We sub-divide the time sequence in K blocks of equal length M ($L = K \cdot M$) and compute the *block averaged IDF* $u_r(s)$ according to Eq. (1) for each block and its mean $u_{rm} = K^{-1} \sum_{s=1}^{K} u_r(s)$. We show that the width of the distribution $P(u_r)$ reaches a maximum in the vicinity of the melting transition. This behavior is well captured by the second moment of $u_r(s)$, i.e. the *variance of the block averaged interparticle distance fluctuations* $\sigma_{u_r}^2 = \langle u_r^2(s)\rangle - \langle u_r(s)\rangle^2$.

[1] A. Proykova and R. S. Berry, J. Phys. B: At., Mol. Opt. Phys. 39, R167 (2006).
[2] V. M. Bedanov, G. V. Gadiyak, Y. E. Lozovik, Phys. Lett. A 109, 289 (1985).
[3] R. D. Etters and J. Kaelberer, Phys. Rev. A 11, 1068 (1975).
[4] D. D. Frantz, J. Chem. Phys. 115, 6136 (2001).
[5] J.Böning, A. Filinov, P.Ludwig, H.Baumgartner, M.Bonitz and Yu.E.Lozovik, Phys. Rev. Lett. 100, 113401 (2008).

French Martin
Water Under Extreme Conditions

Martin French (1), Ronald Redmer (1), Thomas R. Mattsson (2)
(1) Universität Rostock, (2) Sandia National Laboratories

We present the first all-electron QMD simulations of water in the ultra-high-pressure regime up to conditions typical for the deep interior of Jupiter and Saturn. We calculate the equation of state and the Hugoniot curve and study the structural properties via pair correlation functions and self-diffusion coefficients. In the ultra-dense superionic phase, we find a continuous transition in the protonic structure. Water at conditions of Jupiter's core (i.e. 20000 K, 50 Mbar, 11 g/cm^3) forms a fluid dense plasma. Supported by the DFG within SFB 652. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States DOE's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Gryaznov Victor
Model for Equation of State of Warm Dense Hydrogen

V. Gryaznov 1, I. Iosilevskiy 2
1 Institute of Problems of Chemical Physics RAS, Chernogolovka, Russia 2 Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia

Quasi-chemical representation ("chemical picture") proved to be successful in thermodynamic description of gas-like plasmas of weak or moderate Coulomb coupling. Theoretical description of strong Coulomb coupling is more complicated problem. Recent experiments on shock and isentropic explosively driven compression (Sarov) for hydrogen (deuterium) give new impulse to development of thermodynamic theory for dense partially ionized hydrogen. Improved model for equation of state (EOS) of warm dense hydrogen was developed in frames of quasi-chemical representation of hydrogen as multi-component strongly interacted mixture of atoms, molecules, ions and electrons. Interaction potentials for intense short-range repulsion of neutral particles were used in simplified form (soft sphere model). Parameters of these potentials for atoms and molecules were chosen in accordance with non-empirical atom-atomic approximation (E. Yakub). Coulomb corrections were used via modified pseudopotential model (I. Iosilevskiy). Partial degeneracy of electrons was taken into account also. At low-temperatures the model is in satisfactory agreement with experimental data on room-temperature isotherm. High-temperature behaviour of the model was examined by comparison with whole collection of recent experimental data on shock compression of solid and liquid deuterium (M. Knudson et al., R. Trunin et al.) as well as for pre-compressed gaseous deuterium (M. Mochalov et al.). The strong test for the model is comparison of pressure-density dependence of quasi-isentropically compressed deuterium with latest experimental data from Sarov (Fortov et al. PRL, 2007). Present theoretical model proved to give satisfactory agreement of low and high-density branches of deuterium isentrope with this experiment in pressure-density plane despite of parameters of isentrope were not obtained yet. In frames of the model density jump between the low and high branches follows by noticeable increase of Coulomb nonideality. Presently calculated thermodynamic properties of strongly coupled isentropically compressed deuterium fluid (thermal and caloric EOS, equilibrium composition etc.) are presented and discussed.

Holst Bastian
Hydrogen and Helium at Megabar Pressures: Demixing and Metallization

Bastian Holst Winfried Lorenzen Nadine Nettelmann Ronald Redmer
Institut fuer Physik Universitaet Rostock 18051 Rostock

We study the behaviour of fluid hydrogen, helium and their mixtures at high pressures to improve the current understanding of giant planets like Jupiter and Saturn which is based on interior models that reproduce the observational constraints such as mass, radius, rotational period, and gravitational moments. Phase separation and demixing into a helium-rich and a helium-poor phase would explain the lower helium content in Jupiterś outer region and the high luminosity of Saturn which exceeds the theoretical value based on homogeneous models by about 50%. This phenomenon would also fix the location of layer boundaries which are, up to now, free parameters to meet observational constraints. We present new results of ab initio quantum molecular dynamics simulations based on finite-temperature density functional theory for fluid hydrogen-helium mixtures at megabar pressures. We find conclusive evidence that demixing of hydrogen and helium occurs in both planets so that this fundamental problem has now been settled. We furthermore present new conductivity and reflectivity results for fluid hydrogen and discuss the nonmetal-to-metal transition which occurs at about 0.4 Mbar. We compare with experimental data and predictions of chemical models.

Iosilevskiy Igor
Plasma polarization in massive astrophysical objects

Igor Iosilevskiy
Moscow Institute of Physics and Technology (State University), Dolgoprudny, Moscow region, 141700, Russia

We discuss macroscopic plasma polarization created in massive astrophysical bodies by gravitation and other inertial forces. It creates quasi-stationary electrostatic field of the same order (counted per one proton) as the force, which gives rise to polarization, in particular gravitation. This effect was established long ago by Pannekoek and Rosseland (1922-1924) for the case of ideal, isothermal and non-degenerated plasma in outer layers of a star. Their approach based on solution of several separate ('individual') equations of hydrostatic equilibrium for partial pressures for each species of particles. This approach was extrapolated later (see for example, Bilsten et al.) on dense and degenerated interiors of compact stars. Present work presumes non-correctness of this extrapolation. We consider generalized multi-component density functional approach combined with simplified 'local densities approximation' for separate densities of positive and negative charged species. The resulting extremum condition for thermodynamic potential corresponds to equivalent condition for generalized (electro-)chemical potential and/or condition of equilibrium for all the forces acting on the charged particles. In this latter form new non-traditional 'non-ideality' force due to strong Coulomb non-ideality is added to two traditionally competing forces: gravitational and electrostatic ones. Present approach leads to final expression for average electrostatic field, which does not restricted by condition of ideal and non-degenerated plasmas. Presently the effect of non-isothermality, magnetic field influence and relativistic effects are not taken into account. The resulting formula in present work reproduces two known limiting cases: for degenerated and non-degenerated ideal gas and leads to additional effects. The most interesting sequences of these effects on structure, thermo- and hydrodynamics of a star are under discussion.

Kalman Gabor

Strongly Coupled Plasma Techniques for Quark-Gluon Plasmas

G. J. Kalman (1), P. Hartmann (2), Z. Donko (2) and P. Levai (3, 4)

(1) Dept. of Physics, Boston College, Chestnut Hill, MA 02467, USA (2) Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, Konkoly-Thege Miklos str. 29-33, H 1121 Budapest, Hungary (3) KFKI Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences, Konkoly-Thege Miklos str. 29-33, H 1121 Budapest,Hungary (4) Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, Konkoly-Thege Miklos str. 29-33, H 1121 Budapest, Hungary

With the discovery that the quark-gluon plasma created in the RHIC experiments are strongly coupled (sQGP), several groups have proposed to exploit the similarity between the issues that arise in the strongly coupled electromagnetic plasma and in the sQGP [1,2,3]. Here we illustrate the use of two interrelated major techniques, the analytic Quasi Localized Approximation (QLCA) method [4] and computer simulation by using Molecular Dynamics (MD) [5].

While the QLCA is built upon the classical dynamical equations for the particles, the exact quantum dynamics of the color λ-matrices can be easily incorporated in the formalism. The QLCA analysis of the coupled dynamics of the particles and of the color matrices reveals remarkable collective mode structures. For example, the similarity between the algebras of the λ-matrices and the spin σ-matrices suggests the existence of a color oscillation, analogous to spin waves in systems of magnetic dipoles. The prerequisite for such an excitation to develop is the existence of a non-vanishing average of one of the λ_A components. In a strongly interacting quark-system this is assured by the conditional average of the fluctuations in the vicinity of a selected colored particle. Application of the QLCA formalism to this process describes the dispersion relation for this collective mode as a functional of the static color-color pair correlation functions (PCF) of the system.

In the MD program, extending our model used in earlier studies [3] , so that it combines the exact classical dynamics of the particles coupled with the dynamics of the λ-matrices, as described by their Heisenberg equations, will provide the static PCF, as well as the dynamical mass density, color density and current correlations (cf. [6]). The former can generate the input required for the QLCA analysis, while latter can deliver a direct insight into the nature and structure of the collective modes in the system, which, in turn, may importantly affect its transport coefficients.

Supported by Grants from NSF and OTKA.

[1] B. A. Gelman, E. V. Shuryak and I. Zahed, Phys. Rev. C **74** 044908, 044909 (2006).
[2] M. H. Thoma, Nucl. Phys. A **774** 307 (2006).
[3] P. Hartmann, Z. Donkó, G.J. Kalman and P. Lévai, Nucl. Phys. A **774** 881 (2006).
[4] K. I. Golden and G. J. Kalman, Phys. Plasmas **7** 14 (2000).
[5] Z. Donko, this Conference.
[6] M. Hoffmann et al., Phys. Lett. B **478** 161 (2000).

Kraeft Wolf-Dietrich
Equation of State for Dense Strongly Coupled Hydrogen

W.D. Kraeft(1), K. Wuensch (2), D.O. Gericke (2), J. Vorberger (2)
(1)Institut fuer Physik, Universitaet Rostock, D-18051 Rostock, Germany (2)Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, UK

Knowledge of the equation of state (EOS) provides information on properties needed for hydrodynamic simulations of laser and ion beam experiments, for predictions in inertial fusion, and modelling of giant gas planets. The latter, for example, has been shown to be very sensitive to EOS models in the high pressure region. Although many methods exist to calculate the EOS, they are all only applicable in certain parameter regions and one cannot rely on a single technique for the full parameter range needed for modelling high energy density experiments or giant gas planets.
Here, we study a variety of approaches designed to calculate the EOS for fully ionized plasmas including quantum statistics and strong correlations (for the ions) in a consistent way. The aim is an approach that is applicable from low to very high densities. In particular, we develop a method that gives the correct Debye-Hueckel law in the low density (classical) case and the correct quantum limit for highly degenerate electrons for plasmas under extreme pressures. For that goal, we combine quantum statistical Green's function methods and classical integral equations using effective (quantum) potentials. Within two hybrid approaches we try to incorporate the advantages of both, namely correct statistics for any degeneracy (from the Greenś function theory) and strong correlations in the ionic subsystem (HNC).

Redmer Ronald
The Complex Behavior of Fluid Lithium

Andre Kietzmann (1), Ronald Redmer (2), Michael P. Desjarlais (2) and Thomas R. Mattsson (2)
(1) University of Rostock, Institute of Physics, D-18051 Rostock, Germany (2) Sandia National Laboratories, Albuquerque, NM 87185-1186, USA

Lithium is a prototypical simple metal at standard conditions. However, by changing the density towards expanded or compressed states, the electrical conductivity shows strong variations. We have performed quantum molecular dyanmics simulations for fluid lithium covering a wide range of densities and temperatures in order to derive the equation of state, the pair correlation functions, and the density of states [1]. The electrical conductivity changes from values typical for a non-metallic expanded fluid at low densities via the fluid metal region at normal conditions up to a degenerate electron liquid at high densities. We find a largely ordered ion structure at ultra-high densities reflecting a multi-center bonding situation in the liquid as predicted earlier for solid lithium [2].

[1] A. Kietzmann, R. Redmer, M.P. Desjarlais, and T.R. Mattsson, submitted.
[2] J.B. Neaton and N.W. Ashcroft, Nature 400, 141 (1999).

Sakan Nenad
The cut-off Coulomb potential in optical dense hydrogen plasma continuum cross section calculation

Nenad M. Sakan(1), Anatoly A. Mihajlov(1), Vadim M. Adamyan(2)
(1)Institute of Physics, Pregrevica 118, Zemun, 11080 Belgrade, Serbia (2)Department of Theoretical Physics, Odessa National University, Dvoryanska 2, 65026 Odessa, Ukraine

The applicability of cut-off coulomb potential for the calculation of bond-free and free free continuous optical cross sections in hydrogen plasma is discussed in this work. It is expected that this method would be applicable for interpretation of experimental data. The studied plasma dense highly non ideal where inside of ions self sphere r_n, exists only one electron. In other words the Debye radii (r_D) is comparable to the self sphere radii $r_D \sim r_n$. The calculations are compared to experimental data for dense hydrogen plasma that fulfills the request for single electron in ion sphere radii.

Sreckovic Vladimir
Electrical conductivity of strongly non-ideal plasma in an external HF electric field

I.M.Tkachenko(1), V.M.Adamyan(2), N.M.Sakan(3), V.A.Sreckovic(3), D.Sulic(3) and A.A.Mihajlov(3)
(1)Polytechnic University of Valencia, Spain (2)Department of Theoretical Physics, Odessa University, 270057 Odessa, Ukraine (3)Institute of Physics, Pregrevica 118, Zemun, Belgrade, Serbia

The problem of determination of high frequency (HF) electro conductivity for a long time now has been drawing attention of researchers as well because of own importance as well because of the fact that, over this quantity all other HF characteristics can be expressed [1]. Naturally, the way of HF conductivity determination depends on inner plasma conditions: electronic density, temperature, the presence of external magnetic field and etc. The case of the dense non-ideal plasma is the specific one, which come out as very difficult for study and lightly investigated till now. Previously, in [2], we developed RPA method for calculation of HF electro conductivity in the range of low and moderately non-ideal plasmas: $10^{17} < N_e < 10^{19} cm^{-3}$, $10^3 K < T < 10^4 K$. The examined range of frequencies covered the microwave and far-infrared region. Because the numerical procedure for calculation of the HF conductivity within RPA method is very complicated, we invest some effort to develop the alternative simple one, which would be suitably for operative laboratory use. We extend the range of frequencies(UV) and electron densities and cover the area of very hight and extreme el. densities: $10^{21} < N_e < 10^{24} cm^{-3}$, $10^3 K < T < 10^5 K$. The results of calculations of HF el. conductivity obtained by means of all mentioned methods are presented and compared with existing data in literature. In our previously mentioned papers [1], [2] , expressions for HF electro conductivity was represented in the parameterized form suitably for comparison with results obtained from classic Drude-Lorentz formula. Following that, in this work expressions for HF electro conductivity obtained within RPA method was introduced in quasi Drude format. Also we presented the deviation of HF electro conductivity obtained with alternative simple method from corresponding Drude.

[1]V.M.Adamyan,Z.Djuric,A.A.Mihajlov,N.M.Sakan and I.M.Tkachenko J.Phys.D 37,1896(2004).
[2]A.A.Mihajlov,Z.Djuric, V.M.Adamyan and N.M.Sakan,J.Phys.D 34,3139(2001).

Sreckovic Vladimir
High-frequency characteristics of strongly non-ideal plasma in an external HF electric field

V.M.Adamyan(1),A.A.Mihajlov(2),V.A.Sreckovic(2), N.M.Sakan(2) and I.M.Tkachenko(3)
(1)Department of Theoretical Physics, Odessa University, 270057 Odessa, Ukraine (2)Institute of Physics, Pregrevica 118, Zemun, Belgrade, Serbia (3)Polytechnic University of Valencia, Spain

The numerical procedure for calculation of the HF conductivity within RPA method is very complicated. Because of that we invest some effort to develop the alternative simple one, which would be suitably for operative use. On the basis of obtained numerically calculated values, for the dense strongly non-ideal plasma conductivity in an external HF electric field we determine the electrical permeability and the coefficients of refractivity and reflectivity of plasma. Previously, in [1], [2], we calculate electrical permeability and the coefficients of refractivity and reflectivity of plasma in the range of low and moderately non-ideal plasmas: $10^{17} < N_e < 10^{19} cm^{-3}$, $10^3 K < T < 10^4 K$. Here we extend the range of frequencies(UV) and electron densities and cover the area of very hight and extreme el. densities: $10^{21} < N_e < 10^{24} cm^{-3}$, $10^3 K < T < 10^5 K$. The parameterized form of representation of the results is suitable for further usage and for experimental verification.

[1] V.M. Adamyan, D. Grubor, A.A. Mihajlov, N.M. Sakan, V.A. Sreckovic and I.M. Tkachenko, J. Phys. A 39, 4401 (2006).
[2] V.M. Adamyan, Z. Djuric, A.A. Mihajlov, N.M. Sakan and I.M. Tkachenko J.Phys. D 37, 1896 (2004).

Starostin Andrey N.
Influence of electrons degeneracy on the contribution of bound states to the non-ideal hydrogen plasma EOS.

A.N. Starostin(1), V.E. Fortov(2), V.K. Gryaznov(2), I.L. Iosilevskiy(3), V.C. Roerich(1)
(1) Troitsk Institute for Innovation and Fusion Research, Troitsk, Russia (2) Institute of Problems of Chemical Physics RAS, Chernogolovka, Russia (3) Moscow Institute of Physics and Technology, Dolgoprudnyi, Russia

Equation of state for a non-ideal hydrogen plasma [1] is developed to account the influence of degenerated electrons on the contribution of bound states. Derivation of corresponding partition function is presented. The new form of the bound states contribution to plasma pressure is compared with previously used expressions for the case of the solar plasma. The model EOS also includes the relativistic corrections, radiation pressure in plasma, the Coulomb interaction in the Debye-Hückel approximation together with diffraction and exchange corrections, and the contribution of scattering states. Sound speed and adiabatic index values are compared with those obtained using SAHA-S model [2].

[1] Starostin A.N. and Roerich V.C. *JETP* **100**(1) (2005) 165–198. [2] Gryaznov V.K., et al. *J. Phys. A: Math. Gen.* **39** (2006) 4459–4464.

Vorob'ev Vladimir
Self-Consistent Electric Field Inside Ordered Dust Structures

V. S. Vorob'ev, O. F. Petrov, and V. E. Fortov
Joint Institute of High Temperatures, Russian Academy of Sciences (IVTAN), Moscow, 125412 Russia

We report finding a self-consistent electric field of electrons, ions, and dust grains inside an ordered dust cloud in glow discharge, and show that this field differs radically from that of an isolated grain. Besides, the screening radius coincides with the size of Wigner–Seitz cell. The value of potential necessary for containing dust particles in the direction perpendicular to the discharge axis is estimated. We show that the interaction potential energy of a system of ordered dust grains has a form characteristic of ionic crystals. Critical parameters for a liquid-like dust structure are estimated. The correlation function of dust grains obtained via this approach is compared with the measured function.

Quantum phase transitions in 2D Coulomb systems

Punnoose Alexander
Quantum phase transitions in two dimensions and the metal-insulator transition.

Alexander Punnoose
City College of New York 160 Convent Ave Marshak Hall Rm 309A New York, NY 10031 USA

Early speculation that an electron gas in two dimensions is always an insulator was upset when experiments in relatively clean systems showed clear signs of metallic behavior. Further systematic experiments showed clear signatures of a metal to insulator transition (2DMIT) as the density is reduced, forcing us to re-examine the role of electron-electron interactions and disorder. Recently, we uncovered a new quantum critical point in a dirty Fermi-liquid, which I will argue with the help of new experimental evidence, corresponds to the 2DMIT.

Kravchenko Sergey
Interplay of Disorder and Interactions in Two-Dimensional Semiconductors

S. V. Kravchenko
Northeastern University, Boston, USA

The discovery [1] of the metallic state and metal-to-insulator transition in two-dimensional electron systems challenged the veracity of one of the most influential conjectures in the modern condensed matter physics, which states that [2] "in two dimensions, there is no true metallic behavior". Recently, a two-parameter scaling theory comprehensively describing the metal-to-insulator transition in two dimensions was developed by Punnoose and Finkelstein [3]. I will report experimental verification of the basis of this theory. In particular, we have demonstrated, for the first time, that strong electron-electron interactions stabilize the "forbidden" metallic state in two dimensions. We have also found that as a result of the interplay between the interactions and disorder, both the resistance and the effective interactions become temperature dependent. We have constructed a resistance-interaction flow diagram of the metal-insulator transition that clearly reveals a quantum critical point, as predicted in Ref. [3]. The metallic side of this diagram is accurately described by the theory without any fitting parameters. On the opposite side of the transition, the disorder prevails and the interactions "die" in the low-temperature limit giving rise to the insulating state.

[1] S.V. Kravchenko et al., Phys. Rev. B 50, 8039 (1994).
[2] E. Abrahams, P.W. Anderson, D.C. Licciardello and T.V. Ramakrishnan, Phys. Rev. Lett. 42, 673 (1979).
[3] A. Punnoose and A.M. Finkelstein, Science 310, 289 (2005)

Geldart D. J. Wallace
Quantum Critical Point Description of 2D Metal-Insulator Transitions

D. J. W. Geldart(1,4), D. Neilson (2,3,4)
(1) Department of Physics and Atmospheric Science, Dalhousie University, Halifax, NS B3H3J5, Canada, (2) Dipartimento di Fisica, Università di Camerino, I-62032 Camerino, Italy, (3) NEST-CNR-INFM, Scuola Normale Superiore, Piazza dei Cavalieri 7, 56126 Pisa, Italy, (4) School of Physics, University of New South Wales, Sydney 2052, Australia

We develop a quantum critical point description of the metal-insulator transition phenomenon in 2D electron systems. The vicinity of the quantum critical point where the correlation length ξ and the thermal length L_T are both large exhibits scaling properties. The various sectors associated with this critical region of the phase diagram are characterized by the ratio ξ/L_T and the sign of $n - n_c$, where n and n_c are the density and critical density, respectively. In addition to critical behaviour in the usual quantum critical sector (large ξ/L_T with either sign of $n - n_c$), we predict critical behaviour also in the low temperature insulator critical sector (small ξ/L_T and $n - n_c < 0$). We focus attention primarily on obtaining new information on critical properties from this insulating neighbourhood of the quantum critical point. A scaling equation is derived for the resistivity $\rho(n, T)$ in the insulating critical sector. We show that both the dynamical critical exponent z and the correlation length critical exponent ν can then be determined from published $\rho(n, T)$ data from a single experiment in the insulator critical sector. These critical exponents obtained from the insulating critical sector must agree with those obtained from the quantum critical sector since both regions are controlled by the same quantum critical point. This provides important consistency checks, both for data analysis and the interpretation of experiments. We find that the value of $z\nu$ from the insulator critical sector is consistent with the T dependence of $\rho(n, T)$ in the quantum critical sector. This consistency supports the presence of a quantum critical point in the 2D metal-insulator transition systems.

Neilson David
Tunnelling and hopping between metallic domains in the two-dimensional metal-insulator transition

David Neilson
Dipartimento di Fisica, Università di Camerino, Camerino(MC), Italy CNR-INFM, Pisa 56126, Italy School of Physics, University of New South Wales, Sydney 2052, Australia

We investigate transport in 2D mesoscopic electron systems with disorder assuming a percolation mechanism connecting through a network of metallic domains. The size of the domains is determined by the level of disorder and the strength of the electron correlations. The domains are linked for transport by two mechanisms that compete, thermally activated hopping and quantum tunneling. We calculate the transmission across the potential barriers between the domains. Using recent data from transport measurements in mesoscopic 2D systems, we obtain saturation of the temperature dependent resistivity at $T \sim 1$ K and consistent values for the spatial dimensions of the domains and the average variation in the random disorder potential.

De Palo Stefania
Spin susceptibility in Si-MOSFETs: the role of the valley degeneracy and disorder

S. De Palo (1,2), M. Marchi (1,3), S. Moroni (1,3), G.Senatore (1,2)
(1) INFM-CNR DEMOCRITOS National Simulation Center, Trieste, Italy, (2) Dipartimento di Fisica Teorica, Universita' di Trieste, Strada Costiera 11, 34014 Trieste, Italy, (3) International School for Advanced Studies (SISSA), I-34014 Trieste, Italy

We examine the effects of device details on the spin susceptibility of a two-dimensional (2D) electron gas (EG) to model Si-MOSFET's, resorting to extensive QMC simulations [1]. We find that valley degeneracy suppresses the spin susceptibility in a substantial manner with respect to the conventional one-valley EG [2]. Comparison with experiments [3] at high and medium density reveals a reasonable agreement, which becomes very good once the thickness appropriate to actual devices is included. However at low density the results for a clean two-valley EG do not show any sharp increase of the spin susceptibility as found in the experiments when approaching the metal-insulator transition. The only device detail not included that might be responsible for such an apparent divergence is likely to be the disorder. To determine the disorder parameters which are not experimentally known we fit the measured mobility, within the Born approximation, over the whole experimental range. Inclusion of such a disorder in second-order perturbation theory yields a spin susceptibility in excellent agreement with experiment.

[1] M. Marchi, S. De Palo, S. Moroni, and Gaetano Senatore; to be published.
[2] C. Attaccalite, S. Moroni, P. Gori-Giorgi, and G. B. Bachelet; Phys. Rev. Lett. 88 256601 (2002).
[3] A. A. Shashkin, S. Anissimova, M. R. Sakr, S. V. Kravchenko, V. T. Dolgopolov, and T. M. Klapwijk ; Phys. Rev. Lett. 96, 036403 (2006) and reference therein.

Quantum phase transitions in 2D Coulomb systems - Posters

Bernu Bernard
Metal-insulator transition in the two-dimensional fully polarized homogeneous electron gas from Hartree-Fock solutions

B. Bernu (1), F. Delyon (2), M. Duneau (2), M. Holzmann (3)
(1) LPTMC, UMR 7600 of CNRS, Université P. et M. Curie, Paris, France,
(2) CPHT, UMR 7644 of CNRS, École Polytechnique, Palaiseau, France,
(3) LPMMC, UMR 5493 of CNRS, Université J. Fourier, Grenoble, France

We determine the ground state of the two-dimensional, fully polarized electron gas within the Hartree-Fock approximation without imposing any particular symmetries on the solutions. At low electronic densities, the Wigner crystal solution is stable, but for higher densities (r_s less than ~ 2.6) we obtain a ground state of different symmetry: the charge density forms a triangular lattice with about 11% more sites than electrons. We argue that this conducting state with broken translational symmetry remains the ground state of the high density region in the thermodynamic limit giving rise to a metal to insulator transition.

Ciftja Orion
Analytic wave functions for the half-filled lowest Landau level

Orion Ciftja
Department of Physics, Prairie View A&M University, Prairie View, Texas 77446, USA

We consider a two-dimensional strongly correlated electronic system subject to strong perpendicular magnetic field and introduce a class of many-body wave functions suitable for the half-filled lowest Landau level state. These wave functions consist of states that lie entirely in the lowest Landau level. The simplicity of these wave functions permits exact closed-form solutions for standard two-dimensional systems of electrons in disk geometry. We obtain analytic expressions for the ground state energy and other quantities of such a system as a function of the number of electrons. We discuss possible ways to improve the quality of such wave functions and lower their energy near the composite fermions values.

Filinov Vladimir
Structures of quantum 2D electron - hole plasmas

V.S. Filinov(1), H. Fehske(3), M. Bonitz(2), V. Fortov(1), P. Levashov(1)
(1) Joint Institute for High Temperatures, Russian Academy of Sciences, Izhorskaya 13/19, Moscow 127412, Russia, (2) Christian-Albrechts-Universität zu Kiel, Institut für Theoretische Physik und Astrophysik, Leibnizstrasse 15, 24098 Kiel, Germany, (3) Institut für Physik, Ernst-Moritz-Arndt-Universität Greifswald, Domstrasse 10a, D-17489 Greifswald, Germany

We present results for 2D electron-hole plasmas in the wide region of temperature, density and electron to hole mass ratio. Our calculations include region of appearance and decay of the bound state (excitons and biexcitons), Mott transition from neutral e–h plasma to metallic–like clusters, formation from clusters the hexatic-like liquid and then formation of the crystal-like lattice and at very low temperatures transition of this "latice" to antiferromagnetic structure. In our studies we use the direct quantum path integral Monte Carlo method developed in our previous works for studying 3D strongly correlated two component plasma media as hydrogen and electron-hole plasmas at finite temperature.

Ludwig Patrick
Strongly correlated spatially indirect electron-hole states in quantum wells

Patrick Ludwig (1,2), A. V. Filinov (1), K. Balzer (1), M. Bonitz (1) and H. Stolz (2)
(1) Christian-Albrechts-Universität zu Kiel, Institut für Theoretische Physik und Astrophysik, Leibnizstraße 15, 24098 Kiel, Germany
(2) Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock, Germany

We investigate structural phase transitions of mesoscopic ensembles of optically excited indirect excitons in a single quantum well (QW) where the spatial separation of electrons and holes is produced by an electricfield. The lateral confinement arises from the quantum confined Stark effect with a typical trap size being of the order of several micrometers [1]. At low temperatures and small electron-hole separation distances the electrons and holes form stable spatially indirect excitons with a permanent dipole moment d [2]. We show that for $d > 3a_B$ the exciton-exciton repulsion is sufficiently large to stabilize the excitons into a crystalline state. We analyse in detail the structural transitions by varying the mass ratio [3], density [4] (e.g. via the trap frequency), temperature, electron-hole separation (e.g. via the electric field strength or the QW width) and excitation intensity (exciton number). We predict the parameter range for experiments on ZnSe-based QWs where the excitons are stable and form a mesoscopic or macroscopic crystal.

[1] P. Ludwig, A. Filinov, M. Bonitz, and H. Stolz, phys. stat. sol. (b) 243, No. 10, 2363 (2006).
[2] A. Filinov, P. Ludwig, Yu.E. Lozovik, M. Bonitz, and H. Stolz, J. Phys: Conf. Series 35, 197 (2006).
[3] P. Ludwig, A. Filinov, Yu. Lozovik, H. Stolz, and M. Bonitz, Contrib. Plasma Phys. 47, 335 (2007).
[4] A. Filinov, M. Bonitz, P. Ludwig, and Yu.E. Lozovik, phys. stat. sol. (c) 3, No. 7, 2457 (2006).

Totsuji Hiroo

Structure and Spin-Polarization of Finite Two-Dimensional Systems of Electrons at Zero and Finite Temperatures: Simulations based on Classical-Map Hypernetted Chain Method

Hiroo Totsuji, Takashi Miyake, Kenta Nakanishi, Chieko Totsuji, and Kenji Tsuruta
Okayama University, Okayama 700-8530, Japan

Finite systems of electrons in two dimensions are analyzed and their structures and spin-polarization characteristics are obtained. We map these systems onto classical systems and perform Monte Carlo and molecular dynamics simulations on the latter. As the mapping, the classical-map hypernetted chain (CHNC) method is applied. The elements of mapping is the introduction of the quantum temperature which expresses the effect of degeneracy, the introduction of the additional potential which expresses the Pauli exclusion principle between electrons of the same spin, and the modification of the Coulomb potential to include the effect of quantum diffraction. This mapping has been proposed by Dharma-wardana and Perrot for the purpose of analysis of electron systems by integral equations. We apply this mapping to numerical simulations of electron systems which are without the translational symmetry and/or geometrically complex: For these systems, direct simulations are more suited compared with the integral equation approach. Confirming that the ground state energies of infinite systems at zero temperature obtained by *ab initio* quantum simulations are reproduced to a good accuracy, we apply the mapping with the same parameters to our systems of electrons. (1) In the case of electrons confined by the two-dimensional parabolic and other potentials, we observe that, when the confinement becomes sufficiently weak, electrons are spin-polarized and the critical density of polarization is significantly higher than the one for infinite system at which we have a possibility of polarization $r_s \sim 3 \cdot 10^1$ (quantum simulations are not conclusive on whether the infinite system polarizes or not). We also observe the formation of Wigner lattice in these finite systems by analyzing the electron distribution in our system and the critical values of crystallization are obtained corresponding to appropriate definition of lattice formation. (2) The case of layered systems are also analyzed. (3) In this method, the case of finite temperatures can be treated without much increased difficulty. The results will be presented and the effect will be discussed. Finite two-dimensional systems of electrons such as quantum dots are expected to play an important role as element of electronic devices. The results of these simulations will be helpful in designing those devices operating at ordinary temperatures.

Graphene and Electron bilayers

Katsnelson Mikhail
Graphene: New bridge between condensed matter and quantum electrodynamics

M. I. Katsnelson
Institute for Molecules and Materials, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ, Nijmegen, The Netherlands

Graphene, which is the first example of truly two-dimensional crystals turns out to be a gapless semiconductor with unique electronic properties. The charge carriers in graphene demonstrate a charge-conjugation symmetry between electrons and holes and possess an internal degree of freedom similar to "chirality" of ultrarelativistic elementary particles. This provides a new bridge between condensed matter physics and quantum electrodynamics and opens a way to investigate in experiments with graphene some exotic quantum relativistic phenomena hardly reachable otherwise. I consider various examples of relations between graphene physics and QED, including the Klein paradox and chiral tunneling; vacuum polarization around charge impurities and relativistic atomic collapse; the Atiyah – Singer index theorem, in relation with anomalous quantum Hall effect in single- and bilayer graphene; the "Zitterbewegung" related with minimal metallic conductivity and leading to anomalous Kondo-like corrections to transport properties. Due to thermal fluctuations in two-dimensional systems, the graphene membrane turns out to be intrinsically corrugated which leads to an interesting problem of two-dimensional massless Dirac fermions in a curved space.

Andrei Eva
Scanning tunneling spectroscopy and transport measurements in graphene

Eva Y. Andrei
Rutgers University U.S.A.

The recent discovery of methods to isolate graphene (a single layer of graphite) has opened the way to bench-top studies of quasi-particles whose properties are governed by quantum-relativistic dynamics (Dirac fermions). I will describe scanning tunneling spectroscopy and transport experiments that give direct access to the unique properties of the Dirac fermions in graphene. Our findings include evidence of their chiral nature, effects of electron-phonon and electron-electron interactions.

Khveshchenko Dmitri
Coulomb Interacting Dirac Fermions in Graphene

D.V.Khveshchenko
Dept. of Physics and Astronomy, UNC-Chapel Hill

Recent advances in microfabrication of graphitic samples that are only a few carbon layers thick have made it possible to test the early theoretical predictions of the anomalous properties of this system. The electronic band structure of graphene is characterized by the presence of a pair of inequivalent nodal points where the valence and conduction bands touch as a pair of opposing cones with the opening angle given by the Fermi velocity. The low-energy quasiparticle excitations in the vicinity of such nodal points can be described as Dirac fermions which carry a physical spin 1/2 and possess an additional orbital ("pseudo-spin" or "valley") quantum number corresponding to the double degeneracy of the electronic Bloch states in graphene. In a (nearly) degenerate semimetal such as graphene, the Coulomb interactions are expected to play an important role due to their poor screening. Besides, any interplay between the Coulomb interactions and disorder is likely to further modify the behavior of an idealized (clean and non-interacting) Dirac fermion system. In this work, we focus on the effects of strong Coulomb correlations and make a number of specific experimental predictions that can be used for interpreting the results of tunneling, photoemission, and magnetization measurements.

Polini Marco
Many-body Physics on a Charming Flatland

Marco Polini
NEST-CNR-INFM and Scuola Normale Superiore di Pisa, Italy

Graphene, a flat monolayer of Carbon atoms tightly packed into a two-dimensional honeycomb lattice, provides a realization of two-dimensional chiral massless Dirac fermions which interact via nearly instantaneous Coulomb interactions. The chirality changes the quantum mechanics of the particles and is responsible for a number of unusual properties. In this talk I will discuss how chirality is also behind unusual effects in the electron correlation physics of doped graphene sheets, including enhanced quasiparticle velocities [1], and suppressed charge and spin susceptibilities [2]. I will also show that in graphene states near the Dirac point interact strongly with plasmons with a characteristic frequency that scales with the sheetś Fermi energy and depends on its interaction coupling constant [3], partially explaining prominent features of recent angle-resolved photoemission-spectroscopy data. I will finally comment on the importance of using exchange-correlation potentials based on the properties of a chiral two-dimensional electron gas in density-functional-theory applications to graphene nanostructures such as ribbons and quantum dots [4]. Our conclusions are based on microscopic ground-state-energy calculations within the so-called Random Phase Approximation (RPA) and on GW-RPA calculations of the quasiparticle self-energy.

[1] M. Polini, R. Asgari, Y. Barlas, T. Pereg-Barnea, and A.H. MacDonald, Solid State Commun. 143, 58 (2007).
[2] Y. Barlas, T. Pereg-Barnea, M. Polini, R. Asgari, and A.H. MacDonald, Phys. Rev. Lett. 98, 236601 (2007).
[3] M. Polini, R. Asgari, G. Borghi, Y. Barlas, T. Pereg-Barnea, and A.H. MacDonald, Phys. Rev. B 77, 081411(R) (2008).
[4] M. Polini, A. Tomadin, R. Asgari, and A.H. MacDonald, arXiv:0803.4150v1 (2008).

Rainis Diego
Andreev reflection in graphene nanoribbons

Diego Rainis(1) Fabio Taddei(1) Fabrizio Dolcini(1) Marco Polini(1) Rosario Fazio(1,2)
(1)NEST-CNR-INFM and Scuola Normale Superiore, I-56126 Pisa, Italy (2)International School for Advanced Studies (SISSA), via Beirut 2-4, I-34014 Trieste, Italy

Andreev reflection in graphene/superconductor hybrid systems has been shown to exhibit unusual features stemming from the honeycomb-lattice arrangement of Carbon atoms in two-dimensional graphene crystals. In this talk we study Andreev reflection in graphene nanoribbon/superconductor hybrid junctions. We show by using a tight-binding approach and the scattering formalism that notable differences emerge due to finite-size effects with respect to the 2D case. We find in fact that the low-energy band structure of the ribbon is responsible for the absence of Andreev reflection in a wide range of energies (~ 0.2 eV in a 10 nm wide ribbon) when the Fermi energy lies at the Dirac level. Shifting the Fermi energy of an amount U away from the Dirac level restores a finite value of the Andreev-reflection coefficient only in an energy window $\sim 2U$ around the Fermi energy.

Strinati Giancarlo

BCS-BEC crossover in electron-hole bilayers

P. Pieri, D. Neilson, and G. C. Strinati
Department of Physics University of Camerino Camerino (MC), Italy

The BCS-BEC crossover, from the BCS limit of highly overlapping Cooper pairs to the BEC limit of non-overlapping tightly bound pairs, was originally theoretically conceived for excitons in semiconductors but never experimentally realized in these systems. Recently, interest in this crossover has surged owing to its realization with ultra-cold (neutral) Fermi atoms, for which the inter-particle attraction can be varied essentially at will with the use of Fano-Feshbach resonances. At about the same time, however, experimental advances with electron-hole bilayers made it possible to get fuller control of the densities of electrons and holes in the separate layers, so that a revival of the interest in the BCS-BEC crossover for excitons in these systems seems appropriate at this time. To this end, we have studied [1] the occurrence of excitonic superfluidity in an electron-hole bilayer at zero temperature, for which we have identified the appropriate crossover region in the BCS-BEC phase diagram. By varying further the electron and hole densities independently, we have analyzed a number of phases that occur mainly in the crossover region. The jump of the electron and hole chemical potentials when their densities cross is then proposed as the criterion for the onset of superfluidity.

[1] P. Pieri, D. Neilson, and G. C. Strinati, Phys. Rev. B 75, 113301 2007.

Hamilton Alex

The effect of screening long-range Coulomb interactions on the metallic behaviour in two-dimensional holes

A.R. Hamilton (1), L.H. Ho (1), W.R. Clarke (1), A.P. Micolich (1), R. Danneau (1), O. Klochan (1), M.Y. Simmons (1), M. Pepper (2) and D.A. Ritchie (2)

(1) School of Physics, University of New South Wales, Sydney, NSW 2052, Australia, (2) Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom

The ground state of a 2D system is determined by the ratio rs of the inter-particle Coulomb energy to the kinetic energy, with the regimes rs 0, rs 10, and rs 100 corresponding to the gas, liquid and solid phases of the 2D system respectively. Recently, much effort has gone into studying the phase diagram of 2D systems, focussing on the role of interactions and disorder. An elegant experimental probe is to use an adjacent metallic ground-plane to screen the long-range Coulomb interactions, and thereby study how the length-scale of the interactions controls the ground state. Previous studies have used ground-plane screening to probe the melting of the Wigner crystal state of electrons on liquid helium,[1] and hopping transport in the insulating regime in an ultra-low density 2D hole system (2DHS).[2] Given that the 2D metal-insulator transition is often attributed to Coulomb interaction, it would be interesting to perform a corresponding study for the metallic state of a 2DHS.

For semiconductor devices the simplest way to vary the distance between the 2D system and the ground plane is to use a series of different samples. However this results in a different disorder potential for each of the 2D systems, which introduces undesirable complications since the measured transport properties are strongly affected by disorder. Furthermore studying the metallic state presents a significant technical challenge because the distance between the ground-plane and the 2DHS must be small (¡ 50 nm) to achieve effective screening. We have developed a new technique utilizing a double quantum well heterostructure that allows us to study the effect of a nearby ground-plane on the metallic state in a GaAs two-dimensional hole system (2DHS) in a single sample and measurement cool-down, thereby maintaining a constant disorder potential.[3] In contrast to recent measurements of the effect of ground-plane screening in the insulating regime, we find surprisingly little effect on the metallic state when we change the distance between the 2DHS and the nearby ground-plane. We discuss this unexpected result and its relation to screening effects.

[1] H.-W. Jiang and A. J. Dahm, Surf. Sci. 196, 1 (1988).
[2] J. Huang, D. S. Novikov, D. C. Tsui, L. N. Pfeiffer and K. W. West, cond-mat/0610320.
[3] L.H. Ho, W.R. Clarke, A.P. Micolich, et al, Phys. Rev. B. Rapid Communications (in press).

Lozovik Yury

Coherent phases and collective phenomena of electron-hole system in graphene and semiconductor nanostructures

Yu.E.Lozovik

Institute of Spectroscopy, 142190 Moscow region, Troitsk, Russia lozovik.isan.troitsk.ru

The coherent phase of electrons (e) and holes (h) due to their Coulomb attraction in two parallel, independently gated graphene sheets separated by a barrier is considered. At weak coupling, there exist BCS-like pair-condensed state. Despite the fact that electrons and holes behave like massless Dirac fermions, the problem of BCS-like electron-hole pairing in graphene bilayer turns out to be rather similar to that in coupled semiconductor quantum wells. The essential distinctions are due to Berry phase of electronic wave functions and different screening properties. The energy gap in one-particle excitation spectrum for different interlayer distances and carrier concentrations is calculated. Influence of disorder is discussed. At large dielectric susceptibility of surrounding medium, the weak coupling regime holds even at arbitrarily small carrier concentrations contrary to the case of nonzero effective masses. Strong coupled regime is discussed. Localized electron-hole pairs are absent in graphene, thus the behavior of the system versus coupling strength is cardinally different from usual BCS-BEC crossover. The e-h condensation in coupled graphene sheets can be observed through essential rise of e-h drag, Josephson-like phenomena etc. Single and coupled graphene layers in strong perpendicular magnetic field is discussed. Magnetoexciton spectra and their effective magnetic mass in one and coupled graphene layers are studied in detail. The energy spectrum of collective excitations and superfluid transition of dipolar magnetoexciton system in coupled graphene sheets are studied. Composite fermion system properties in graphene and coupled graphene sheets in strong magnetic field corresponding to 1/2 and 1/2 +1/2 Landau level filling respectively is studied. Instabilities in the system, particularly, coherent state formation originated from composite fermions pairing are analyzed. Plasma oscillations and instabilities in graphene will be discussed. Similarity and distinction from phenomena in semiconductor coupled quantum wells will be discussed.

[1] K. Geim, K.S. Novoselov, Nature Materials 6, 183 (2007).
[2] M.Katsnelson, Materials Today 10, 20 (2007).
[3] Yu.E.Lozovik, A.A.Sokolik, JETP Lett., 87, No.1, 55-59 (2008).
[4] O.L. Berman, Yu.E. Lozovik, G.Gumbs, Phys. Rev. B 77, 155433 (2008).
[5] Yu. E. Lozovik, V.I. Yudson, JETP Lett. 22 274 (1975); Zh. Éksp. Teor. Fiz. 71, 738 (1976).
[6] J.S. Thakur, D. Neilson, M.P. Das, Phys.Rev.B57, 1801(1998).

Golden Kenneth
Collective Excitations in a Two-Dimensional Dipole System

Kenneth Golden (1), Gabor J. Kalman (2), Zoltan Donko (3) and Peter Hartmann (3)
(1)Department of Mathematics and Statistics, College of Engineering and Mathematical Sciences, University of Vermont, Burlington, Vermont 05401-1455, USA (2)Department of Physics, Boston College, Chestnut Hill, Massachusetts 02467, USA (3)Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, H-1525 Budapest, P. O. Box 49, Hungary

Over the past few years, two-dimensional (2D) dipole systems have attracted a great deal of interest [1], primarily as a model for strongly coupled electron-hole bilayers [2]. We address the question of collective excitations in 2D dipolar systems. The main issue is that such systems have no RPA limit and calculations have to include correlations from the outset. We focus on the longitudinal collective mode representing the density oscillations of the dipoles. Our theoretical approach is based on the Quasi-Localized Charge Approximation (QLCA) adapted to point dipole systems interacting through a $1/r^3$ potential at arbitrary degeneracy. Our analytical calculation is accompanied by classical Molecular Dynamics (MD) simulations. Concentrating on the long-wavelength $q \to 0$ regime, we have found that the collective excitation exhibits an acoustic behavior with a phase velocity that is wholly maintained by particle correlations and varies linearly with the dipole moment p. This is in marked contrast to other predictions based on an RPA-like argument, but it is similar to what has been recently reported for the closely spaced classical electron-hole bilayer [2].
Recent quantum Monte Carlo (QMC) simulations [1] provide data on the ground-state correlation energy for the zero-temperature bosonic dipole system from which we are able to generate a collective mode dispersion for such a system through the QLCA formalism. QMC simulations also provide information on the static structure function that can be used to infer the collective mode dispersion via the Feynman relation. We find that the QLCA acoustic phase velocities in the quantum and classical domains are very close. However, the QLCA and Feynman approximations for the phase velocity differ by as much as 34%, which may be due to difficulties in measuring the static structure function data accurately at small wavenumbers.
Our classical MD simulations can be extended to finite wavenumbers up to $qa \approx 4$ ($a = 1/\sqrt{\pi n}$) showing a roton-like behavior. Comparison with the QMC dispersion generated through the Feynman relation [1] shows a remarkably good quantitative agreement between the two.
Supported by NSF and OTKA.

[1] G. E. Astrakharchik, J. Boronat, I. L. Kurbakov, and Yu. E. Lozovik, Phys. Rev. Lett. 98, 060405 (2007).
[2] G. J. Kalman, P. Hartmann, Z. Donko, and K. I. Golden, Phys. Rev. Lett. 98, 236801 (2007).

Graphene and Electron bilayers - Posters

Al-essa Izzat
Hydrogenation of thermally evaporated silicon a-Si:H by new technique

Izzat.M. AL-Essa
Department of physics ,Collage of science University of Baghdad ,Iraq

Hydrogenated amorphous silicon have been successfully prepared. We present a comprehensive work being carried on a-Si:H prepared by thermal evaporation with glow discharge (Plasma of hydrogen). In this case we used Balzer coating unit BA510 attached to a control system BL100 for substrate temperature ,pressure ,thickness and rate of deposition . The hydrogenation have been done by a new technique under different parameters such as (pressure, rate of deposition, rate of flow of hydrogen, the distance between capacitance electrodes and biasing voltage). The aim of this new technique is to obtain a-Si:H thin film with low density of state, stable and controllable function of annealing temperature, substrate temperature and doping percentages in order to be used in a variety of optoelectronic devices.

Kalman Gabor
The Relativistic Strongly Coupled Plasma - Application to Graphene?

G. J. Kalman (1), K. I. Golden (2), P. Hartmann (3) and Z. Donko (3)
(1)Dept. of Physics, Boston College, Chestnut Hill, MA 02467, USA (2)Dept. of Mathematics and Statistics, College of Engineering and Mathematical Sciences, University of Vermont, Burlington, VT 05401-1455, USA (3)Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, Konkoly-Thege Miklos str. 29-33, H 1121 Budapest, Hungary

The emergence of graphene as a system with a moderately strongly coupled electron liquid emulating relativistic behavior has refocused interest in the dynamics of relativistic and ultra relativistic plasmas. Studies of such systems within the RPA (or Vlasov approximation), both on the classical and on the quantum level, with and without magnetic field have been available for a long time (see e.g. [1]). Also, a fair understanding of the dynamics of non-relativistic strongly coupled plasmas is by now available [2,3]. The combination of the relativistic and strong coupling behaviors is expected, however, to lead to qualitatively new physical effects. Focusing now on an ultra relativistic system, the origin of the difference between the weakly coupled and strongly coupled plasmas can be found in the momentum (rather than mass) dependence of the plasma frequency. While in the weakly coupled system it is sufficient to work with the average momentum, in the strongly coupled case one is faced with a system resembling that of an infinite number of coupled oscillators. The description of this model emerges naturally from the relativistic extension of the Quasi Localized Charge Approximation (rQLCA): the plasmon dispersions derived from the conventional QLCA and from the rQLCA are, however, substantially different, the difference being more important at strong coupling values.
We have performed classical Molecular Dynamics simulations of the ultra relativistic plasma for a wide range of coupling values. Dynamical density, current and momentum-current correlations have been measured and the plasmon dispersion has been determined from these spectra. The findings for $\omega(k)$ and for the damping differ markedly from those in the non relativistic case at comparable coupling values: they are compared with the theoretical results from the QLCA and rQLCA calculations.
While the prevailing coupling values around $(r_s) = 2$ in graphene [4] do not seem to be high enough to bring out dramatic differences between the various approaches, the deviation of the plasmon dispersion from the RPA prediction should become a measurable effect.
Supported by Grants from NSF and OTKA.

[1] R. Cover, G. Kalman and P. Bakshi, Phys. Rev D **20**, 3015 (1979) .
[2] K. I. Golden and G. J. Kalman, Phys. Plasmas, **7**, 14 (2000).
[3] Z. Donko, this Conference.
[4] A. K. Geim and K. S. Novoselov, Nature Materials **6**, 183 (2007).

Karmakar Biswajit

Correlation-Driven First-Order Qunatum Phase Transition in Quantum Hall Bilayers

B. Karmakar (1), V. Pellegrini (1), A. Pinczuk (2,3), L. N. Pfeiffer (3) and K. W. West (3).
(1)NEST CNR-INFM and Scuola Normale Superiore, I-56126, Pisa, Italy (2)Dept. of Appl. Phys. And Appl. Math., Dept. of Phys., Columbia Unoversity, New Work 10027 (3)Bell Laboratories, Alcatel-Lucent, Murray Hill, New Jersey 07974

A quantum phase transition from an incompressible quantum Hall phase to a compressible metal phase occurs in electron bilayers at total filling factor $\nu_T = 1$ [1]. In mean-field theory the instability is triggered by the collapse of a tunneling gap Δ_{SAS} linked to the softening of an excitation mode induced by inter- and intra-layer Coulomb interactions [2], suggesting the occurrence of a continuous quantum phase transition. Recently, we showed that at finite Δ_{SAS} the $\nu_T = 1$ incompressible phase is an excitonic collective state that emerges in response to strong inter-layer correlation [3]. The order parameter measures the ground-state excitonic density and can be determined in inelastic light scattering experiments from measurements of the energy splitting between spin excitations [3]. Recent work also showed that the non-quantum Hall compressible phase is a bilayer composite fermion metal phase due to intra-layer correlation [4]. This talk reports the recent determination of the order parameters at the quantum phase transition by precise inelastic light scattering experiments at mk temperatures. The boundary of the quantum phase transition at $\nu_T = 1$ is accessed by changing Δ_{SAS}, by finely tuning an in-plane component of the magnetic field . We discovered that the phase transformation is discontinous. In spite of some phase coexistence close to the phase boundary due to residual disorder [5], we can probe selectively the properties of the excitonic state and measure the evolution of the excitonic order parameter with remarkable accuracy. The observed discontinuity demonstrates that a correlation-induced first-order quantum phase transition separates the excitonic quantum Hall phase from the compressible composite-fermion metal phase that is stabilized by intra-layer correlations. These studies offer key insights on physics of correlated electron phases near a quantum phase transition. The intriguing interplay between inter-layer and intra-layer correlations in electron bilayers results in competing order-parameters near a quantum critical point.

[1] G.S. Boebinger et al., Phys. Rev. Lett. 64, 1793 (1990); S. Murphy, et al., Phys. Rev. Lett. 72, 728 (1994).
[2] A.H. MacDonald et al., Phys. Rev. Lett. 65, 775 (1990); L. Brey, Phys. Rev. Lett. 65, 903 (1990).
[3] S. Luin et al. Phys. Rev. Lett. 94, 146804 (2005).
[4] B. Karmakar et al. Solid State Comm. 143, 499 (2007).
[5] S. Luin, Phys. Rev. Lett. 97, 216802 (2006).

Mesoscopic and nanoscopic systems

Manninen Matti
Strongly correlated electrons in quantum dots and rings

M. Manninen
Nanoscience Center, P.O.Box 35 FIN-40014 University of Jyvaskyla Finland

The quantum phenomena of electrons in quantum dots and rings is reviewed. In semiconductor quantum dots electrons are confined by long range electric fields and, consequently, they are trapped in a nearly harmonic confinement. This seemingly simple system, a few interacting electron in a two or three dimensional harmonic confinement, shows surprisingly many quantum effects arising from the strong correlation between the electrons. In the low-density limit the electrons localize into a Wigner crystal, while at higher densities spin-density waves or spontaneous partial polarization can occur.
In a magnetic field the orbital angular momentum of the electrons increases. This leads to states related to the integer or fractional quantum Hall effect. At small angular momenta the rotating system has free vortices. When the angular increases vortices will be attached to the electrons forming composite particles and the system reaches the fractional quantum Hall regime. Eventually, at very high angular momenta, the electrons localize and form a classical system, where the excitations are vibrational modes of the Wigner lattice. The localization of electrons and vortices are closely related and lead to similar excitation spectrum.
In quantum rings the one-dimensionality of the confining potential emphasizes the quantum effects. In a strictly one-dimensional system fermions with same spin can not pass each other. This means, for example, that even noninteracting particles seem to interact and, for example, show vibrational spectrum. The physics of quantum rings is discussed with help of simple models.

Bonitz Michael
Quantum many-body effects in artificial atoms and electron-hole bilayers

M. Bonitz, A. Filinov, J. Böning, K. Balzer, P. Ludwig
Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität, Leibnizstr. 15, D-24098 Kiel, Germany

Charged particles in trapping potentials tend to from concentric rings (or shells in 3D) which resemble atoms. These "artificial atoms" have a number of interesting features missing in real atoms: by controlling the confinement strength they can be transformed from a weakly coupled state to a strongly coupled "phase" which resembles a Wigner crystal[1]. This is observed even for small particle numbers of the order of 20. There solid-like and liquid-like behavior can be detected by a modified version of the Lindemann parameter for the pair distance fluctuations[1]. After reviewing these results, we will discuss "artificial atoms" formed of Bose particles. Here, also crystallization is observed but, in addition, the system exhibits superfluidity. We demonstrate that, depending on the particle number, the superfluid component is concentrated in the cluster core or at the edge[2].
Finally, we present results for quantum bilayers of electrons and holes. This systems has a rich variety of phases. Particularly interesting is the possibility to control the pair interaction and the effective spin statistics: while at large layer separation the system consists of Coulomb interacting fermions, at smaller distances a transition to composite bosons with nearly dipole interaction is observed. Our results are based on first principle path integral Monte Carlo simulations which are complemented by time-dependent Nonequilibrium Greens functions methods [3].

[1] A. Filinov, M. Bonitzm, and Yu.E. Lozovik, Phys. Rev. Lett. 86, 3851 (2001) [Böning et al.(2008)Böning, Filinov, Ludwig, Baumgartner, Bonitz, and Lozovik] J. Böning, A. Filinov, P. Ludwig, H. Baumgartner, M. Bonitz, and Y. E. Lozovik, Phys. Rev. Lett. 100, 113401 (2008).
[2] A. Filinov, J. Böning, M. Bonitz, and Yu.E. Lozovik, Phys. Rev. B (2008).
[3] P. Ludwig, K. Balzer, A. Filinov, H. Stolz, and M. Bonitz, New J. Phys. (2008)

Casula Michele
Correlation effects in quasi one dimensional electron wires

[1] Department of Physics, University of Illinois at Urbana-Champaign, 1110 W. Green St, Urbana, IL 61801, USA
[2] INFM Democritos National Simulation Center, Trieste, Italy
[3] Dipartimento di Fisica Teorica dell' Università di Trieste, Strada Costiera 11, 34014 Trieste, Italy
Luke Shulenburger,[1] *Michele Casula,*[1] *Gaetano Senatore,*[2,3] *and Richard M. Martin*[1]

We explore the role of electron correlation in quasi one dimensional quantum wires as the range of the interaction potential is changed and their thickness is varied by performing exact quantum Monte Carlo simulations at various electronic densities. First, we take into account unscreened interactions with a long range $1/x$ tail, where there is a crossover from a liquid to a quasi Wigner crystal state as the density decreases. Then we study the effect of screening and electron correlations in the double quantum wire experiment [Steinberg *et al.*, Phys. Rev. B **77**, 113307 (2006)], by explicitly including the finite length of the system in our simulations. We find that decreasing the electron density drives the system from a liquid to a state with quite strong $4k_F$ correlations. This crossover takes place around 22 μm^{-1}, near the density where the electron localization occurs in the experiment. The charge and spin velocities are also found in good agreement with the experimental findings in the proximity of the crossover.

Das Mukunda
Vortex matter phase transition in mesoscopic type II superconductors

Mukunda P Das
Department of Theoretical Physics Institute of Advanced Studies The Australian National University Canberra, ACT 0200 Australia

The magnetic phase diagram for a normal type II superconductor has several important features, most notable of which are the lower and upper critical fields. Between the lower and upper critical fields the magnetic field lines penetrate the superconductor in the form of discrete field quantum, known as a vortex. As the magnetic field increases, more of field lines penetrate the superconductor, so the density of the vortices increases. The vortices organise in order to minimise the total free energy what is called an Abrikosov vortex lattice. The lattice spacing depends on the temperature T and applied magnetic field H. If there is a lattice at T≠0, it has to thermally melt undergoing a solid to a fluid phase transition.
In high temperature cuprate superconductors the phase diagram of (H∼T) is far more complex. It has been widely explored yielding a rich variety of new physics. The coherence length being about a nanometer size, the dominant correlations are in the mesoscopic scale. In this talk I shall discuss a microscopic approach how to study freezing of the vortices of a vortex fluid to a vortex solid phase. One will note that this is opposite to the phenomenon of melting. The method I shall employ is the density functional theory of freezing. Applied magnetic field fixes the areal density of the vortices and I shall require the intra- and inter-pair potentials of the vortices. Some details of calculated and experimental phase diagrams will be presented.

Kempa Krzysztof
Plasmon polaritons in nanostructures

K. Kempa
Boston College, USA

Interaction of light with matter involves various charge excitations. These, in turn couple to photons, and thus modify the light propagation, leading to polaritons. This process is enhanced in nanostructures, which due to their sizes provide necessary momentum for an efficient coupling. This talk will discuss various plasmonic effects in nanostructures, and the corresponding polaritons. Conceptually simplest are metallic nanoparticles, which support the Mie-type plasmon resonances. A much more complicated system is the carbon nanotube, which supports numerous plasmon modes, and in which a cross-dimensional (1D to 2D to 3D) cross-over occurs. To a special category belong polaritonic crystals, simplest of which is the 3D point dipole crystal, host to various polaritonic, plasmonic and photonic modes. Finally, the discretely guided effective medium will be discussed, based on nano-coaxial, subwavelength transmission lines. This medium allows for a remarkable manipulation of light, which could lead to optical lensing free of the diffraction limitation, image encoding, negative refraction, cloaking, etc.

Mesoscopic and nanoscopic systems - Posters

Filinov Alexey

Controlling the local superfluid density in bosonic Coulomb and dipole clusters

A. Filinov(1,2), J. Boening(1), Yu.E. Lozovik(2) and M. Bonitz(1)
(1) Institut fuer Theoretische Physik und Astrophysik, University Kiel, D-24098, Kiel, Germany (2) Laboratory of Spectroscopy of Nanostructures, Institute of Spectroscopy, 142190, Troitsk, Russia

When a few tens of charged particles are trapped in a circular electrostatic potential at low temperature they form concentric shells resembling atoms. These "artificial atoms" can be easily controlled by varying the confinement strength [1]. Here we study these systems for the case when the particles are bosons by the path integral Monte Carlo method. We compute the superfluid density and its spatial distribution. We show that while in the gas phase the superfluid fractions on different shells are similar, in the radially ordered, but orientationally disordered state [1], the shells contribute very differently. The local superfluid density [2] can be concentrated either on the inner or outer region of the cluster by varying the confinement strength or with a proper choice of the particle number. The observed effect vanishes with the increase of the particle number due to emergence of hexagonal symmetry, causing a systematic reduction of the superfluid fraction on the inner shells.

[1] A. Filinov, M. Bonitz, and Yu.E. Lozovik, Phys. Rev. Lett. 86, 3851 (2001).
[2] Y. Kwon, F. Paesani, and K.B. Whaley, Phys. Rev. B 74, 174522 (2006).
[3] A. Filinov, J. Böning, M.Bonitz and Yu.E. Lozovik, submitted to Phys.Rev.Lett. / cond-mat arXiv: 0711.1255.

Dusty plasmas and colloids

Goree John
An introduction to dusty plasmas, with a comparison to colloids

John Goree
Department of Physics and Astronomy The University of Iowa Iowa, Iowa 52242 USA

Dusty plasma is an ionized gas containing small particles of solid matter, or "dust." It is sometimes called "complex plasma," in analogy to the scientific field of "complex fluids." One type of complex fluid is a colloidal suspension, which is similar to dusty plasmas except that the particles are immersed in a liquid solvent instead of a rarefied gas.
In the first part of the talk, I will explain the basics of dusty plasmas and colloids and compare them. In both cases a particle constantly collects positive and negative charge carriers from the surrounding medium, and ultimately it acquires a large charge, usually with the same polarity as the lighter of the two charge carriers, except for cases such as dust in space plasmas where UV light causes photoemission. In both dusty plasmas and colloidal suspensions, there is mutual Coulomb repulsion, which is screened by a Debye length established by the charge carriers in the surrounding medium. Containment prevents these repulsive particles from moving to infinity. The particles can self-organize in a crystalline lattice, i.e., a colloidal crystal. Experimenters can track particle motion using video microscopy, and record particle positions and velocities. The experimenter can manipulate particles using the radiation pressure force of laser beams.
Dusty plasmas differ from colloids in several ways. One prominent difference is damping. The much more massive liquid solvent of a colloid causes particle motion to be heavily overdamped, while the rarefied gas of a dusty plasma allows underdamped motion. Thermal equilibrium is another difference: in colloids particles have the same temperature as the solvent, but in plasmas the particle motion, the temperature of the gas, and the temperature of the charge carriers (electrons and ions) can all be different. The dusty plasma is usually a driven dissipative system, while the colloidal suspension is in equilibrium. Another difference is the Coulomb shielding, which is often anisotropic in dusty plasma due to ion flow. Finally, gravity has a profound effect in plasmas, while in colloids it is mostly offset by buoyancy.
In the second part of the talk, I will present results from 2D dusty plasma experiments. Random motion in 2D dusty plasmas is shown to exhibit superdiffusion and non-Gaussian statistics. The melting of a crystal exhibits solid superheating.
Work is supported by NASA and the US Dept. of Energy.

Melzer Andre
Finite particles systems in strongly coupled dusty plasmas

Andre Melzer(1) Sebastian Kaeding(1) Yuriy Ivanov(1) Dietmar Block(2) Alexander Piel(2)
(1)Insitute of Physics, University Greifswald (2)IEAP, University Kiel

Particle-containing (dusty) plasmas are ideal systems to study effects of strong coupling where the electrostatic interaction between neighboring particles by far exceeds their thermal energy. In dusty plasmas, microspheres are trapped in a gaseous plasma. There the particles attain a high negative charge due to the continuous inflow of plasma electrons and ions. Due to this high charge the particles can crystallize into ordered structures. The size and time scales of these systems allow a detailed observation by video microscopy.
Recently, dust systems with a small, finite, number of particles have attracted growing interest because of their interesting properties. For dust clusters the boundary imposed by the confinement plays a crucial role. As a consequence, the structure of dust clusters drastically depends on the exact particle number N. Simultaneously, the dynamic properties of dust clusters show a strong dependence with particle number.
In this talk, the fundamental properties of finite and extended dusty plasmas are presented. Recent progresses in diagnostic techniques are described which allow to reveal fundamental properties of dust clusters. The structure and the fascinating interplay of structure and dynamical properties will be demonstrated for dust clusters in 1D, 2D and 3D confinement potentials.

Rozenbaum Viktor
Orientational Phenomena in 2D Coulomb Systems

Viktor M. Rozenbaum
Institute of Surface Chemistry, NAS Ukraine, Gen. Naumova Str. 17, Kiev, 03164, Ukraine

A diversity of 2D periodic structures, with their properties governed by Coulomb interactions, arises at phase interfaces, in crystals with large interplane spacings, in thin magnetic films, in nanoarrays, etc. [1-4]. As far as ensembles of polar or nonpolar molecules are concerned, consideration can be restricted to the corresponding terms in the multipole expansion of the Coulomb energy thus affording general analytical treatment.

We derive general relations for electric potentials and dipole-dipole interaction tensors of 2D lattice systems which not only provide the ground-state description of the systems concerned but also enable the elucidation of the low-temperature properties for triangular and square dipole lattices with dipole orientations degenerate in the lattice plane [5]. Due to competing quadrupole and van der Waals dipole-dipole interactions, nonpolar molecules also form various orientational structures on solid surfaces [3]. They are conveniently described in terms of the short-range quasidipole Hamiltonian which reduces, for discrete orientations of long molecular axes, to the Ising-like Hamiltonian with fluctuation interactions and yields a remarkably informative phase diagram [6]. With certain values of the interaction parameters, an exact solution of the statistical problem can be obtained which represents a new intermediate-temperature orientational phase. Its peculiarity is that the long axes of nonpolar molecules are mostly projected onto the same line in the surface plane though without a preferential direction on this selected line [6].

Further research in this area shows promise in the analysis of structures arising in the ensembles of mesoscopic particles such as dusty plasmas with competing electrostatic and magnetic dipole-dipole interactions [7].

[1] V.M. Rozenbaum, V.M. Ogenko, and A.A. Chuiko, Sov. Phys. Usp. 34, 883 (1991).
[2] W. Steele, Chem. Rev. 93, 2355 (1993).
[3] V.M. Rozenbaum and S.H. Lin, Spectroscopy and Dynamics of Orientationally Structured Adsorbates (World Scientific, Singapore, 2002).
[4] E.Y. Vedmedenko, Phys. Stat. Sol. B 244, 1133 (2007).
[5] V.M. Rozenbaum, Sov. Phys. JETP 72, 1028 (1991); Phys. Rev. B 53, 6240 (1996); JETP 84, 368 (1997).
[6] V.M. Rozenbaum, A.N. Morozov, and S.H. Lin, Phys. Rev. B 68, 155405 (2003); Phys. Rev. B 71, 195411 (2005).
[7] J.D. Feldmann, G.J. Kalman, P. Hartmann, and M. Rosenberg, Phys. Rev. Lett. 100, 085001 (2008).

Fisher Michael E.
Near-critical electrolytes: are the charge-charge sum rules obeyed?

Michael E. Fisher
Institute for Physical Science and Technology, University of Maryland, MD 20742, USA

In an electrolyte solution the charge-charge structure factor obeys $S_{ZZ}(k;T,\rho) = 0 + \xi_{Z,1}^2 k^2 - \xi_{Z,2}^4 k^4 + ...$, where $\xi_{Z,1}$ and $\xi_{Z,2}$ are the second- and fourth-moment charge-charge correlation lengths depending on T and the overall ion density ρ. The vanishing of the leading term, the first Stillinger-Lovett (SL) sum rule [1], simply reflects bulk electroneutrality. The second SL rule [1], however, represents the fact that an electrolyte is an it electrical conductor,; the resulting it second-moment condition dictates that $\xi_{Z,1} = \xi_D$ where the Debye screening length ξ_D varies simply as $\sqrt{k_B T/q_0^2\rho}$, q_0 being the elementary ionic charge. But will this rule still hold near fluid-fluid criticality where both the density fluctuations, measured by $S_{NN}(0)$, and the density-density correlation length $\xi_{N,1}$ it diverge?
Our grandcanonical Monte Carlo simulations of a fully it size and it charge symmetric 1:1 (finely-discretized) hard-sphere electrolyte or it restricted primitive model [2], impose electroneutrality, so satisfying the first sum rule automatically. However, careful finite-size scaling analysis of extensive histogram reweighted data [3] indicates that the second moment condition is violated at criticality by approximately 8% with $\xi_{Z,1}^c$ exceeding ξ_D^c. Furthermore, it is found that $\xi_{Z,2}^4$ diverges to $+\infty$ as $T \to T_c$, closely mirroring $S_{NN}(0)$. These findings contradict Generalized Debye-Hückel theory [4] and the exactly soluble charge-it symmetric spherical models [5], both of which support the second-moment condition it at criticality it and the finiteness of the fourth-moment. Nevertheless, the observed behavior is strikingly similar to that of the charge-it asymmetric spherical models [5]. Can one understand these unexpected findings analytically?

[1] F.H. Stillinger and R. Lovett, J. Chem. Phys. **48**, 3858 (1968).
[2] Y.C. Kim and M.E. Fisher, Phys. Rev. Lett. **92**, 185703 (2004).
[3] S.K. Das, Y.C. Kim and M.E. Fisher (to be published).
[4] B.P. Lee and M.E. Fisher, Europhys. Lett. **39**, 611 (1997).
[5] J.-N. Aqua and M.E. Fisher, Phys. Rev. Lett. **92**, 135702 (2004).

Ludwig Patrick
Existence and Vanishing of the Breathing Mode in Strongly Correlated Finite Systems

C. Henning(1), P. Ludwig(1), A. Piel(2), M. Bonitz(1)
(1) Institut fuer Theoretische Physik und Astrophysik, Christian-Albrechts-Universitaet zu Kiel, D-24098 Kiel, Germany, (2) Institut fuer Experimentelle und Angewandte Physik, Christian-Albrechts-Universitaet zu Kiel, D-24098 Kiel, Germany

One of the fundamental eigenmodes of finite interacting systems is the mode of uniform radial expansion and contraction - the "breathing" mode (BM) [1, 2]. Here we show in a general way that this mode exists only under special conditions [3]: i) for harmonically trapped systems with interaction potentials of the form $1/r^\gamma$ ($\gamma \in \mathbb{R}_{\neq 0}$) or $\log(r)$, or ii) for some systems with special symmetry such as single shell systems forming platonic bodies. Deviations from the BM are demonstrated for two examples: clusters interacting with a Lennard-Jones potential and parabolically trapped systems with Yukawa repulsion. We also show that vanishing of the BM leads to the occurence of multiple monopole oscillations which is of importance for experiments.
[1] A. Melzer, M. Klindworth, A. Piel, Phys. Rev. Lett. 87, 115002 (2001).
[2] M. Kong, B. Partoens, and F.M. Peeters, New Jour. Phys. 5, 23 (2003).
[3] C. Henning, K. Fujioka, P. Ludwig, A. Piel, A. Melzer and M. Bonitz, submitted for publication.

Dusty plasmas and colloids - Posters

Apfelbaum Evgeniy
The interaction potential reconstruction in the dusty plasma.

E. M. Apfelbaum.
Joint Institute for High Temperatures of Russian Academy of Sciences, Izhorskaya 13, stroenie 2 Moscow 125412 RUSSIA.

The problem of the potential reconstruction for the system with known pair correlation function or structure factor is one of the fundamental tasks of the statistical physics (so called inverse task). There is an hypothesis that the behaviour of dusty particles can be considered the same as the behaviour of the microscopic particles. So the determination of the effective interaction potential is also important problem for the physics of complex plasmas. Recently the technique of solution of the inverse task [1] was applied to the results of measurements [2] of pair-correlation functions in dusty plasma. It was shown [3] that the effective potential (which is supposed to be pair-additive) has an attractive branch and it is dependent on the density of dusty particles. One of possible reasons of attraction is the presence of the trap, which contains the dusty particle. So, the influence of the trap field on the form of the effective potential was investigated in this work. It was shown that in some cases the trap field can explain the attraction branch, but it is not the general case.

[1] W. Schommers, Phys. Rev. A 28, 3599 (1983).
[2] V. E. Fortov, A. V. Gavrikov, O. F. Petrov, I. A. Shakhova, V. S. Vorob'ev, Phys. Plasmas 14, 040705 (2007).
[3] E. M. Apfelbaum, Physics of Plasmas 14, 123703 (2007).

Baimbetov Fazylkhan
The pseudopotential model of interaction between dusty plasma particles.

F.B. Baimbetov, E.S. Mukhametkarimov, Z.A. Kudyshev
Department of Physics, al - Farabi Kazakh National University, Almaty, Kazakhstan

In present work the pseudopotential model of interaction between dusty plasma particles, based on dielectric response method, is suggested [1], [2]. Coulomb potential is taken as micropotential of interaction between electrons and ions without taking the surrounding into account; the interaction between electrons (ions) and dusty particles without taking surrounding into account is defined by potential of interaction between electron or ion and its image in dusty particle, which can be easily obtained with help of electric mirror-image method [3]; so called 'bell like' micropotential, which width defined by dusty particle's diameter and height by dusty particle's charge, is responsible for dusty –dusty particles interactions. The dielectric penetration and pseudopotentials are obtained with help of the method, which is represented in works [4], [5]. According to this method the Fourier image of macropotential, which accounts correlation effects, i.e. the influence of the surrounding on first-order interaction, is defined by product of inverse tensor of dielectric penetration and micropotential's Fourier image. It has been shown, that the dependence of obtained pseudopotential (macropotential) of duty – dusty interaction on the distance between dusty particles has an oscillations. Analogously, the radial distribution function has the same view. On basis of obtained results, one can conclude, that suggested pseudopotential model can describe the ordered structure formation in dusty plasma.

[1] Ichimaru S. The basic foundations of plasma physics Atomisdat, 1975, p. 288.
[2] Baimbetov F.B., Arkhipov Yu.V., Davletov A.E. Thermodynamics of partially ionized hydrogen plasmas: Pseudopotential approach in chemical models. Phys. Plasma 2005, v.5, p. 315-321.
[3] Purcell E.M. Electricity and magnetism, Berkley physics course, v.2, Mcgraw – hill book Co., 1975.
[4] Ichimaru S., Mitake S., Tanaka S., X.-Z. Theory of interparticle correlations in dense, high-temperature plasmas.I. General formalism Phys.Rev.A, 1985, v.32, p.1768.
[5] Ichimaru S. Strongly coupled plasma: High – density classical plasmas and degenerate electron liquids Rev.Mod.Phys., 1982, v.54, p.1017.

Bonitz Michael

Emergence of Superdiffusion in Quasi Two-dimensional Yukawa Liquids

T. Ott(1), M. Bonitz(1), Z. Donkó(2), P. Hartmann(2)
(1) Christian-Albrechts-Universität zu Kiel, Institut für Theoretische Physik und Astrophysik (2) Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences

Diffusion is a fundamental transport mechanism, which plays a dominant role in many physical, chemical and biological systems. It is well-known that transport processes may depend significantly on the dimensionality of the systems. Here we study the effect of dimensionality on the self-diffusion in Yukawa liquids, which are widely used as model systems in the physics of complex plasmas. In three-dimensional Yukawa liquids diffusion is known to be normal, and the mean-squared displacement (MSD) of particles $\langle r(t)^2 \rangle \propto t^\alpha$ grows linearly with time, $\alpha = 1$. From the MSD one can obtain a time-independent diffusion coefficient D [1]. When the MSD grows faster than linearly with time, i.e. $\alpha > 1$, the system is termed as "superdiffusive". Recently, such a behaviour has been observed in two-dimensional Yukawa liquids [2].
In this contribution we investigate via Molecular Dynamics (MD) simulation the occurrence of superdiffusion in quasi-two-dimensional Yukawa systems [3], in which the particles' movement in one direction is restricted by a confining force. This situation is also found in many experimental setups. Varying the confinement strength, the behaviour can be tuned continuously from 3D to 2D. Our MD simulations have been carried out for plasma coupling and screening parameter values of $\Gamma = 200$ and $\kappa = 2.0, 3.0$ with $N = 4000 \ldots 16000$ particles. The time interval of the MSD curves is limited to $\omega_p t = 300$ (where ω_p is the 2D plasma frequency). Our results indicate a continuous transition between normal diffusion and superdiffusion, controlled by the strength of the confinement. At high confinement – when a narrow layer is formed – we find an MSD growth exponent $\alpha \approx 1.20$. Similar values have been reported in [2]. With decreasing confinement a value $\alpha \approx 1.05$ is reached. Further details will be given in a forthcoming article [4].

[1] H. Ohta and S. Hamaguchi, Phys. Plasmas 7, 4506 (2000).
[2] B. Liu and J. Goree, Phys. Rev. E 75 016405 (2007), Phys. Rev. Lett. 100 055003 (2008).
[3] Z. Donkó, P. Hartmann and G. J. Kalman, Phys. Rev. E 69 065401 (2004).
[4] T. Ott, Z. Donkó, P. Hartmann and M. Bonitz, Submitted to Phys. Rev. E.

Dyachkov Lev

Rotation of dust plasma clouds in magnetic fields in a dc glow discharge

Lev G. Dyachkov, Mikhail M. Vasiliev, Sergey N. Antipov, Oleg F. Petrov and Vladimir E. Fortov
Joint Institute for High Temperatures, Izhorskaya 13/19, 125412 Moscow, Russia

We have observed the rotation of dust grain clouds in axial magnetic fields in the striation of a dc glow discharge, Dust clouds were formed by monodisperse spherical particles 5.5 μm in diameter. The rotation seems to be a rigid-body one: the angular velocity of all the grains is the same. The rotation velocity depends on the magnetic field B. In low magnetic fields (B 100 G) the angular velocity of the dusty cloud is directed against the magnetic field. With increase in the field, rotation is decelerated and terminated at 500 G. In the field near600 G the dusty cloud was rotated in opposite direct. However, with the further increase in the magnetic field up to 700 G dust particles went from the axial region of the discharge to the discharge periphery with the continuation of the movement around discharge axis. An explanation of the rotation inversion of the dust plasma clouds in the vertical magnetic field in dc discharge is presented. The ions azimuthally drift in the crossed axial magnetic field and radial electric field, and the dust plasma cloud rotation is due to the ion drag force. It is shown that the rotation inversion occurs because of the inversion of the radial ion flux. At low magnetic fields, the radial ion diffusion flux from the axis (where the dust cloud is placed) to walls prevails over the flux absorbed by the dust particles cloud. As the magnetic field increases, the plasma is magnetized and the radial flux toward the wall decreases. At a certain magnetic field value, the total flux on the dust particles becomes larger than the flux generated in the volume of the cloud. Therefore, the inversion of the radial ion flux occurs in the central discharge region and leads to the change in the rotation direction of dust particles. With the further increase in magnetic field the inversion region of the diffusion flux is expanded, the potential trap disappears, and the dusty cloud decays.

Hou Lujing
Non-equilibrium Simulation of Heat Transfer in a Two-Dimensional Dusty Plasma

Lu-Jing Hou and Alexander Piel
IEAP, Christian-Albrechts Universität, Kiel, Germany

We perform here non-equilibrium simulations to study heat transfer in two-dimensional (2D) strongly coupled dusty plasmas (SCDPs) by using Brownian Dynamics method [1], which takes into account both neutral-gas damping and Brownian motion of particles in a self-consistent manner. Our simulation mimics previous experiments [2,3], in which heating and heat transfer were studied by directly observing the dynamics of particles in 2D SCDPs with spatial temperature gradients and scanning laser beams were used to set up these temperature gradients. The similar idea has been considered in our simulation, where an equilibrium of a 2D Yukawa system in solid state is firstly realized, then one part of the system is "heated" by introducing a Gaussian white noise (heater) to a higher temperature falling into either solid or liquid states. By adjusting the strength of the noise, we can realize different temperature differences. It is observed that the temperature in the heated region increases gradually after the heater is turned on, and so evolve the spatial distributions of temperature and density in the whole area. The system reaches a steady state in a period comparable to the relaxation time due to neutral gas damping. In steady state, the temperature profile crossing the interface of the two regions may be well fitted by an exponential curve and this feature is similar to those observed in real experiments [2,3]. Meanwhile, it is found that there is also a difference in density in the two regions: it is lower in the higher temperature region. This difference is too subtle to be observed when the temperature difference is small, but becomes significant otherwise. The density profile in steady state resembles the temperature profile, but with a much smaller scale. Collective motion crossing the interface is also observed, but no conclusive remark can be given before further analysis.

[1] L. J. Hou, Z. L. Mišković, K. Jiang and Y. N. Wang, Phys. Rev. Lett. 96, 255005 (2006).
[2] S. Nunomura, D. Samsonov, S. Zhdanov, and G. Morfill, Phys. Rev. Lett. 95, 025003 (2005).
[3] V. Nosenko, S. Zhdanov, A. V. Ivlev, G. Morfill, J. Goree and A. Piel, Phys. Rev. Lett. 100, 025003 (2008).

Ignatov Alexander
Oscillations of 3D Plasma Clusters

N.G. Gusein-zade, A.M. Ignatov
General Physics Institute, 38, Vavilova str, Moscow, Russia

We consider a system of N particles that are confined in a spherically symmetric potential well and interact with each other via an arbitrary pairwise potential. The equilibrium configurations corresponding to the lowest potential energy are either already known or may be found by numeric methods. Here, we focus on the cluster vibrations. Implementing the theory of point groups we provide the complete classification of oscillations for $N = 4 \ldots 13$. For the most symmetric configurations (N=4, 6, 12), the equilibrium particle positions coincide with the vertices of regular Platonic solids – tetrahedron, octahedron, and icosahedron, respectively. In these cases, we find explicit expressions for all eigenfrequencies and polarizations. For less symmetric configurations, some of the eigenfrequencies only may be written down explicitly for the arbitrary interparticle potential, while others are expressed as eigenvalues of low-dimensional matrices. In the case of the Debye-Huckel interparticle potential, we analyze the dependence of the eigenfrequencies on the Debye length. We also consider the impact excitation of the cluster oscillations (e.g., by the laser pulse) and discuss the inverse problem of whether the unknown interaction potential can be reconstructed from the experimentally measured oscillation frequencies.

Khrapak Sergey
Coulomb-like interactions in complex (dusty) plasmas

S. A. Khrapak, B. A. Klumov, and G. E. Morfill
Max-Planck-Institute fuer extraterrestrische Physik, D-85741, Garching, Germany

This talk is focused on the combined effect of plasma absorption and ion-neutral collisions on the potential energy of interaction between a pair of small grains in isotropic weakly ionized plasmas. A simple linear kinetic model is used to derive the electric potential around an individual grain. Ion-neutral collisions are described using the BGK model collision integral. Ion absorption by a small grain is modelled by the effective point-like sink with the intensity proportional to the effective ion collection cross section. With this model it is demonstrated that at distances exceeding approximately the ion mean free path the potential exhibits unscreened Coulomb-like decay. An additional interaction mechanism associated with the continuous plasma absorption on the grains is a so-called "ion shadowing" attraction, which represents the ion drag force that one grain experiences in an ion flow generated by a neighboring grain, and vice versa. The ion shadowing potential also exhibits Coulomb-like behavior. Thus, in sufficiently rarefied complex plasmas interaction has Coulomb-like character. The long-range asymptote is either repulsive or attractive, depending on plasma parameters. Some important consequences of this result are discussed.

Kodanova Sandugash
Investigation of dust particles orbiting langmuir probe

T.S.Ramazanov(1), S.K.Kodanova(1), O.F.Petrov(2), S.N.Antipov(2), K.N.Dzhumagulova(1), M.K.Dosbolayev(1), A.N.Jumabekov(1)
(1)IETP, Al-Farabi Kazakh National University, 96a, Tole bi St., Almaty, 050012, Kazakhstan (2)Joint Institute of High Temperatures RAS, 13/19 Izhorskaya, Moscow 125412, Russia

In the present work behavior of dust particles near Langmuir cylindrical probe in glow discharge plasma was experimentally investigated. For this purpose the setup on the basis of dc discharge was used in which dust particles acquire negative charge and levitate in the positive column striations [1, 2]. The discharge was created in argon in a vertically oriented cylindrical glass tube with cold electrodes. Single cylindrical Langmuir probe, which is tungsten cylindrical wire 0.1 mm in diameter and 2 mm long, was immersed in the striation in the central part of the discharge perpendicularly to the discharge axis. We used particles of two types: polydisperse Al2O3 particles with diameters 0,002-0,006 mm and monodisperse micron-sized MF-spheres. In order to illuminate the dust particles we used a diode laser beam with wave length 532 nm. In the experiments with probe immersed in dust structures we observed collection of dust particles by attracting probe, i.e. at a positive potential with respect to the local plasma. In this case particles moved from the dust structures directly to the probe and can be repulsed or adhere after impact by probe surface. Particles falling from the top of the discharge to the probe region can collide with attractive probe having some impact parameter. In this case we observed particles trapped on infinite orbits by probe and even particles orbited probe with 1-2 periods. Analysis of orbiting particle trajectories was made and velocities of particles near probe were obtained. Earlier [3], dust particle central motion in the double layer of a cylindrical probe was numerically investigated for the repulsing probe, i.e. at a negative potential with respect to the surrounding plasma. In the present work approach [3] was modified for attracting probe and experimental plasma conditions. Trajectories of dust particles for different initial kinetic energies and impact parameters were calculated. The results were used for diagnostics of discharge plasma parameters as well as for determination of such important dusty plasma characteristic as a dust particle charge.

[1] T.S. Ramazanov, M.K. Dosbolayev, A.N. Jumabekov, O.F. Petrov, S.N. Antipov, Proc. PPPT-5, Minsk, Belarus, 2006. Vol. 1, p. 348.
[2] T.S.Ramazanov, K.N. Dzhumagulova, A.N. Jumabekov, M.K.Dosbolayev Phys.Plasmas, 2008, 15, no.5 (in press).
[3] S.N. Antipov, A.A. Samarian, O.F. Petrov and A.P. Nefedov, Plasma Phys. Rep. 2001, 27, 340.

Kurilenkov Yuri

On hard X-rays bursts and lasings from complex plasmas of nanosecond vacuum discharge

Yu. K. Kurilenkov(1), Yu.B.Konev(1) and M.Skowronek(2)

(1)Joint Institute for High Temperatures of Russian Academy of Sciences, 13/19 Izhorskaya Str., 125412 Moscow, Russia (2)Laboratoire des Plasmas Denses, Universite P.& M. Curie, F-75252 Paris Cedex 05, France

We study x-ray emission and generation of energetic ions at random interelectrode dusty-like media in low energy nanosecond vacuum discharges. The foam-like erosion "target" (nucleated clusters, nano – and micro particles of different size from anode material) is forming automatically at chosen discharge conditions after high voltage applied during the pre-breakdown stage. Current-carrying stage is accompanied by emission of hard X-rays of different intensity from interelectrode complex plasma ensembles [1]. High power density ensembles of clusters are possible candidates for x-rays lasing media. Partial and essential x-ray trapping by ensembles as well as random laser behavior of potentially amplifying media of interelectrode complex plasma are considered. Last scheme with non-resonant feedback by energy have been suggested much earlier [2]. Note the increased interest to random lasers during last decade and some realisations at visible spectra [3]. In our case this scheme assumes the diffusion and partial "random walk" of photons inside of x-rays interelectrode "ball" due to multiple scattering and reflecting in disordered media of cold and number of hot "grains" of any sizes. When the volume gain if available overcomes the surface losses, hard x-ray burst may take place. The properties of ensembles with observed strong hard x-ray bursts which could be interpreted as ASE (super radiance) regimes or random lasing with non-coherent feedback are discussed. Specific mechanisms of pumping and feedback by energy for self-organized interelectrode cluster ensembles are analysed.

[1] Yu.K. Kurilenkov et al. J.Phys. A: Math.& General 39 (2006) 4375.
[2] V. S. Letokhov. Sov. Phys. JETPh 26 no 4(1968) 835; Quantum Electronics 32 (2002) 1065.
[3] N. M. Lavandy et al. Nature, 368 (2002)436; D. Wiersma and A. Lagendijk. Physics World 10 (1997) 33–37; H.Cao. Optics & Photonic News, January 2005, p.24.

Kyrkos Stamatios
Beam-Plasma Interaction and Instabilities in a 2D Yukawa Plasma

Stamatios Kyrkos(1), Gabor J. Kalman(2) and Marlene Rosenberg(3)
(1) Department of Chemistry & Physics, Le Moyne College, 1419 Salt Springs Rd, Syracuse, NY 13214, USA (2) Department of Physics, Boston College, Chestnut Hill, MA 02467, USA (3) Department of Electrical and Computer Engineering, University of California San Diego, La Jolla, CA 92093, USA

In a complex plasma, penetrating charged particle beams may lead to beam-plasma instabilities. When either the plasma or the beam, or both, are strongly interacting[1], the features of the beam-plasma instability are markedly different from those in a weakly coupled plasma. We consider the case when a 2D dusty plasma forms a lattice, and the beam is moving in the lattice plane. Both the grains and the beam particles interact through a realistic Yukawa potential: the beam particles are assumed to be weakly coupled to each other and to the lattice. The system now develops *both a longitudinal and a transverse instability*. Based on the phonon spectrum of a 2D hexagonal Yukawa lattice[2], we determine and compare the transverse and longitudinal growth rates. As a function of the wavenumber, the growth rates exhibit remarkable *gaps*, where no instability is excited. The locations of the gaps are governed by the ratio of the plasma frequencies of the lattice and the beam. The behavior of the growth rates depends, in addition, on the direction of the beam with respect to the principal axes of the lattice, and on the relationship between the beam speed V and the longitudinal and transverse sound speeds. For beam speeds between the longitudinal and transverse sound speeds, the transverse instability becomes more important, as it appears at lower wavenumbers. One scenario for the experimental study of the predicted behavior would involve injecting a beam of light particles propelled by a laser into or over the plasma layer.
Supported by Grants from NSF and from DOE.

[1] G. J. Kalman and M. Rosenberg, J. Phys. A: Math. Gen. **36** 5963 (2003); Stamatios Kyrkos, Gabor J. Kalman, and Marlene Rosenberg, *IEEE Trans. Plasma Sci.* **35**, 342 (2007).
[2] T. Sullivan, G. J. Kalman, S. Kyrkos, P. Bakshi, M. Rosenberg and Z. Donko, J. Phys. A: Math. Gen. **39** 4607 (2006).

Ludwig Patrick
Probability of metastable configurations in spherical three-dimensional Yukawa crystals

H. Kählert, P. Ludwig, H. Baumgartner, and M. Bonitz
Institut für Theoretische Physik und Astrophysik, Christian-Albrechts Universität zu Kiel, Leibnizstr. 15, 24098 Kiel, Germany

Finite strongly coupled systems of charged particles in external traps are of high interest in many fields. Examples include ion crystals [1] or quantum dots [2]. In an isotropic confinement the groundstates are spherical shells (3D) or concentric rings (2D). Here we analyze the occurence probabilities of ground- and metastable states of spherical, three-dimensional Yukawa clusters by means of molecular dynamics (MD) and Monte Carlo (MC) simulations and an analytical method. We find that metastable states can occur with a higher probability than the groundstate, thus confirming recent dusty plasma experiments with so called Yukawa balls [3]. The results strongly depend on the screening parameter of the Yukawa interaction and the damping strength which cools down the particles in the MD simulations. The analytical method [4] allows to gain insight into the mechanisms being responsible for the occurence probabilities in thermodynamic equilibrium. It uses the harmonic approximation and agrees with the MC simulations for low temperatures [5].

[1] D. J. Wineland et. al., Phys. Rev. Lett. 59, 2935 (1987).
[2] A. V. Filinov, M. Bonitz, and Y.E. Lozovik, PRL 86, 3851 (2001).
[3] D. Block, S. Käding, A. Piel, A. Melzer, H. Baumgartner, and M. Bonitz,
& accepted for publication in Physics of Plasmas (2008).
[4] F. Baletto and R. Ferrando, Reviews of Modern Physics 77, 371 (2005).
[5] H. Kählert, P. Ludwig, H. Baumgartner, M. Bonitz, A. Piel, D. Block,
& and A. Melzer, submitted to Physics of Plasmas.

Mayorov Sergey
Modelling of Dust Particle Charging in the Upper Atmosphere

A.M. Ignatov (1), S.A. Maiorov (1), P.P.J.M. Schram (2), S.A.Trigger (3)
(1) General Physics Institute, Moscow, Russia, (2) Eindhoven University of Technology, The Netherlands, (3) Institute for High Temperatures, Moscow, Russia

The noctilucent clouds (NLC) and polar mesosphere summer echoes (PMSE) are associated with the presence of a charged dust in the upper atmosphere. Simulation of the charging of grains is one of the most interesting problems in dusty plasmas with different electron, ion and atom temperatures. The results of ab initio simulations of dusty plasmas are reported. We use molecular dynamics (MD) and particle in cell (PIC) simulation methods to calculate the charge and mean kinetic energy (temperature) of a dust grain in two temperature plasma.

Mitic Slobodan
Local Properties of Complex Plasma Structures

S. Mitic, B. A. Klumov, U. Konopka, M. H. Thoma, G. E. Morfill
Max-Planck-Institute for extraterrestrial Physic, D-85741 Garching, Germany

We report on the first three dimensional (3D) complex plasma structure analysis for an experiment that was performed in an elongated discharge tube in the absence of striations. The low frequency discharge (LFD) was established with 1 kHz alternating DC current through a cylindrical glass tube filled with Neon at 30 Pa. The injected particle cloud consisted of monodisperse microparticles. A scanning laser sheet and a camera were used to determine the particle position in 3D. The observed, cylindrical shaped particle cloud showed an ordered structure with an distinct outer particle shell. The observations are in agreement with performed molecular dynamics simulations.

Petrov Oleg

Dusty Plasmas under Action of External Fields, Radiation and Particle Beams

Oleg F.Petrov and Vladimir E.Fortov

Joint Institute for High Temperatures, Russian Academy of Sciences, Izhorskaya 13-2, Moscow, 125412, Russia E-mail address: ofpetrov@ihed.ras.ru

Dusty plasmas are good experimental models for studying the properties of non-ideal systems and for proofing existing empirical models and numerical results, because, owing to their size, dust particles may be videofilmed, which significantly simplifies the use of direct diagnostic methods. This plasma is a partly ionized gas with negatively or positively charged (10^3-10^5 e) dust particles of micron size (1-10 mcm) that may form quasi-stationary plasma-dust structures similar to a liquid or a solid. Investigations were directed on the study of dusty plasma structures and dynamics on kinetic level under action of different external forces (visible and uv radiation, magnetic and thermal fields, electron beam) in glow rf and dc discharges. Results of experimental study of the dusty plasma kinematic viscosity and the diffusion are presented. The experiments were performed in plasma of a capacitive rf discharge with the particles of different sizes. A uniform flow of a dusty plasma liquid was experimentally realized under laser beam action. Experimental examination of the Einstein-Stokes relation between the viscosity and diffusion constants is carried out. The results of a comparison of the measured diffusion and viscosity constants with the existing data of numerical simulation are considered. The influence of high magnetic field on dusty plasma structures is now of great interest in the field of dusty plasma physics. In the present work the rotation of the dusty clouds and anomalous dust acceleration near the discharge tube wall in strong magnetic field was observed. The dynamical processes in dusty plasma cloud were studied under action of electron beam effecting on dusty plasma parameters such as interparticle distance, mean dust velocity and coupling parameter. Experimental investigations of structures of monodisperse dust particles in dc low-pressure glow discharge at temperatures of liquid nitrogen (77 K) and liquid helium (4.2 K) are presented. Super dense boundary-free dust structure moved in the discharge at 4.2 K was observed. Structural and dynamic characteristics of the cryogenic dust structures were measured. This work was supported by the Russian Foundation for Basic Research (Grants No. 06-02-17532, No. 06-08-01584 and No. 07-02-13600), Grant CRDF RUP2-2891-MO-07 and by Research Program of the Presidium of the Russian Academy of Sciences “Study of Matter under High Energy Densities”.

Rosenberg Marlene
A two-dimensional cryogenic complex plasma?

M. Rosenberg(1) and G. J. Kalman(2)
(1) Dept .of Electrical and Computer Engineering, University of California San Diego - La Jolla, CA 92093, USA (2) Dept. of Physics, Boston College - Chestnut Hill, MA 02467, USA

We propose positioning charged mesoscopic dust grains on the surface of liquid helium [1]. Liquid He provides a nearly ideal flat and quiescent substrate (predominantly in the superfluid phase): it has been used to study 2D electron systems. Besides providing a flat surface, liquid He has low conductivity and extremely weak polarizability, so the dust grains may retain their charge for a relatively long time and the bare Coulomb interaction between the grains would be only slightly affected. The grains are expected to be balanced primarily by surface tension against the gravitational force and may glide on the surface, without being surrounded by a background plasma and neutral atoms.
Further advantages of the proposed system include:
• Systems of charged nanoparticles might also be studied
• The grain could interact via a bare Coulomb interaction; this may open the possibility to study Coulomb (as contrasted with Yukawa) systems with long-range interaction.
• It may be simpler to investigate phenomena involving magnetized dust than in a traditional dusty plasma.
• The system could be well suited for experiments with binary mixtures of particles with different charges or masses.
Some problems one may anticipate include:
• how to charge the dust?
• how to confine the like-charged dust grains?
• what kind of particle to use? -the dust particle should have a lower density than He, so that it can float even if the levitation by surface tension breaks down,
• how to melt the dust crystal? – in order to study the liquid phase, and the solid-liquid phase transition,
• charged dust on the surface may interact with surface ripplons.
Because the density of liquid helium is so low, it may be interesting to investigate the use of other types of cryogenic fluids (argon, nitrogen) with larger mass density, that also have relatively low conductivity and viscosity.
Supported by Grants from DOE and NSF.

[1] M. Rosenberg and G. J. Kalman, Europhys. Lett. 75, 894 (2006)

Schram Pieter
Confinement of plasma particles with Yukawa interaction in the electro-gravitational trap at finite temperature

G.J.F. van Heijst(1), O.F. Petrov(2), P.P.J.M. Schram(1), S.A. Trigger(2) and Yu.P. Vlasov(3)
(1)Eindhoven University of Technology, P.O.Box 513, 5600 MB Eindhoven, The Netherlands e-mail: p.p.j.m.schram@tue.nl
(2)Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow 127412, Russia
(3)State Academy of Transport Communications, Moscow 127994, Russia

The behavior of various objects in a finite volume or in a restricted space is a fascinating problem in physics and biology. Usually the interaction of these objects is essential for their behavior and, in particular, for the density distribution. Typical examples of particle confinement in physics are the hot plasma particles in stellarators and in tokamaks, dusty plasmas in electromagnetic and gravitational traps, ultra-cold Bose and Fermi gases. In the present report we focus on the charged dust particles, which interact by some short-range potential (e.g. Yukawa potential) and are placed in some confined external field, which can be formed by a combination of electromagnetic and gravitational potentials. Depending on the interaction potential, the trap properties and the external parameters, the dust particles can be in an ordered or in a disordered state. An essential interest has recently been evoked by plasma crystals consisting of spherical shells. We investigate analytically and numerically the temperature dependence of the dust particle density in a externally confined one-component Yukawa plasma for various types of traps, different dust temperatures and screening parameters. The notion of average density is introduced for the traps. The results are connected with the recent experiments on the temperature dependence of the dust density in cryogenic discharges.

Schram Pieter
Kinetic Theory of Dusty Plasmas

P.P.J.M. Schram e-mail: p.p.j.m.schram@tue.nl
Eindhoven University of Technology P.O.Box 513 5600 MB Eindhoven The Netherlands

The Kinetic Theory of Dusty Plasmas is derived from Non-Equilibrium Statistical Mechanics based on a generalized Klimontovich formalism, in which the electric charge of the dust particles is introduced as a new phase space variable. As a result the B.B.G.K.Y. hierarchy consists of equations for multiple distribution functions not only of positions and momenta, but also charge. So far this theory is exact. Kinetic equations are derived from the hierarchy equations and Bogolyubov-like boundary conditions, cf. Ref.[1]. An interesting phenomenon discovered is the heating of dust particles to temperatures higher than that of the ambient plasma.
An alternative approach, cf. Ref.[2], is based on a generalized two time master equation. It is a more intuitive than the previous approach. A probability transition function (PTF) plays an essential role. Plausible assumptions regarding the PTF make it possible to derive expressions for diffusion and friction coefficients, which are in good agreement with experimental results and numerical simulations. The method is applicable not only to dusty plasmas, but also to many other systems. It shows interesting phenomena such as anomalous diffusion and in particular circumstances negative friction.
The merits of the two approaches are considered and compared.

[1] P.P.J.M. Schram, S.A. Trigger and A.G. Zagorodny, New microscopic and macroscopic variables in dusty plasmas, New J. Phys.5 (2003) 27 and related papers.
[2] S.A. Trigger, G.J.F. van Heijst, O.F. Petrov and P.P.J.M. Schram, Diffusion in a time dependent external field, Phys.Rev. 77 (2008) 011107 and papers cited there.

Son Eduard
New Concept of Thermodynamics and Transport in Nonequilibrium Dusty Plasma

Eduard Son
Moscow Institute of Physics and Technology

Conventionally theory of Dusty Plasma is based on the theory of equilibrium plasma consisted of free electrons, positive and negative ions and neutral, positive or negative charged dusty particles considered as system in thermodynamical equilibrium. Some essential results are derived for such plasma like existence only repulsive potential between charged elementary or dusty particles [Starostin, Filipiov, et al,], experiments and comparison of measured and calculated transport properties [Fortov, Son, et.al] and many other. In most experiments Dusty Plasma can not be considered as the system in thermodynamic equilibrium on the next reasons: (i) dusty plasma created in nonequilibrium electric dischargers in high electric fields; (ii) dusty plasma exist in the finite area with size where direct and inversed processes are not in equilibrium (any system is in thermodynamic equilibrium if any direct process, like ionization is in a balance with inverse process like recombination). (iii) the number of dusty particles in experiments is small and the dusty particle subsystem can not be considered as thermodynamic system, it is mesosystem (in a sense of existing macro system with number of particles order of Loshmit number (10^19), microsystem with small number of particles (order of 10) and intermediate level (order of 10^2-10^6), (iiii) because of large size of dusty particle surface for collisions with electrons in some cases it could be considered as infinite, and electrons in collisions with the surface have some kind of accommodation and in the case of discharges in molecular gas they change the electron energy distribution function after reflection, creating special Knudsen layers. (i). Dusty Plasma in the Electric Field. some critical values of applied electric field found (ii) The distribution of charged particles near dusty particles and plasma boundaries are governed by local and space processes and could be essentially nonlocal. The general classification size effects, nonlocal approach and results are derived and discussed. (iii) Potential could have attraction area at long distance for the case of dusty particle subsystem not in thermodynamic equilibrium. Newton-Stokes law no more valid. (iiii) The highly nonmaxwellian electron energy distribution is found and results for dusty plasma parameters are discussed.

Sukhinin Gennady

Trapped ions and shielding of dusty particles in a low density non-equilibrium plasma of a glow discharge

Gennady Sukhinin(1,2), Alexander Fedoseev(1), Sergei Antipov(3), Oleg Petrov(3), and Vladimir Fortov(3)

(1) Institute of Thermophysics SB RAS, Lavrentyev Ave.1, Novosibirsk, 630090, Russia (2) Novosibirsk State University, Pirogova Str. 2, Novosibirsk, 630090, Russia (3) Joint Institute for High Temperatures of RAS, Izhorskaya Str.13/19, 127412 Moscow, Russia

The influence of trapped ions on dust particle charging and screening, being extremely important for dusty plasma, requires careful theoretical consideration and experimental verification. In the paper, this problem is investigated for the case of particle charging in a low-pressure DC glow discharge in noble gases. The presented self-consistent model is a development and revision of ideas stated by J. Goree (1992), A. Zobnin *et al.* (2000), M. Lampe (2003), and A.Zagorodny (2003). It takes into account the non-equilibrium character of the electron distribution function, ions drift in DC glow discharge, and the trapping of ions by a charged particle after charge exchange collisions with neutral atoms. The model includes the consideration of balance equation for the creation and destruction of trapped (bound) ions in collisions with neutral atoms in the case when the mean free path of ions is greater than the ion's Debye length. This problem is coupled with the solution of Poisson equation for a self-consistent electric potential. The dust particle charge, the radial distributions of free ions (with positive total energies), trapped or bound ions (with negative total energy), and distribution of electric potential around the charged particle are found. It is shown that the collisional flux of trapped ions only slightly reduces (about 10-15 In experimental investigations based on the electrostatic interaction of two dust particles or the interaction of a charged dust particle with an external electric field, only an effective charge of a dusty particle rather than a proper charge of a particle can be found. In the consideration of dust particles interaction in low density non-equilibrium plasma, the screening provided by trapped ions should be taken into account.

[1] S.A. Khrapak et al., Phys. Rev. E, 72, 016406 (2005).

Totsuji Hiroo

Thermodynamic Instability and Phase Diagrams of Strongly Coupled Yukawa OCP in Deformable Background and Application to Fine Particle (Dusty) Plasmas

Hiroo Totsuji
Okayama University, Okayama 700-8530, Japan

We analyze thermodynamic functions of one-component plasma (OCP) with hard cores embedded in the ambient plasma composed of ions and electrons. The interaction between particles is screened and given by the Yukawa potential. When the coupling between fine particles is sufficiently strong, the isothermal compressibility of the whole system diverges and we have a separation into phases with higher and lower densities and associated critical point. Examples of possible phase diagrams are shown in the plane of Coulomb coupling and screening and compared with phase diagrams expressed in terms of other parameters for usual gas liquid transitions. The relation to the (well known but nothing peculiar happening) divergence of the isothermal compressibility of OCP is discussed. It is pointed out that, when appropriate conditions are satisfied, the critical point can be in the domain of solid phase of Yukawa particles. The behavior of the density fluctuations near the critical point is analyzed and the enhancement of the fluctuation spectrum in the wave number space is predicted. The applicability of these results to fine particle (dusty) plasmas, mixtures of macroscopic fine particles, ions, and electrons, is investigated. The effects of anisotropy and possible attractive parts in the interaction between fine particles are discussed and it is shown that, when three-dimensional isotropic systems of strongly coupled high-density fine particle plasmas are realized, we may be able to observe the above phenomena in fine particle plasmas. The experimental parameters of fine particle plasmas are explicitly related to the characteristic parameters of the Yukawa OCP. Though it is difficult to realize such a system on the ground due to large influence of the gravity on fine particles, we expect the experiment under the condition of microgravity may provide a chance of observation. It has long been known that, in both classical and quantum cases, the isothermal compressibility of OCP diverges at not-so-strong coupling. The divergence is usually masked by the existence of the rigid background which is assumed to deform freely in calculating the compressibility of the OCP. In the case of fine particles plasmas where the role of the background for fine particles is played by classical ions and electrons, we have a chance of experimental observation of the divergence which is intrinsic for OCP.

Theory and simulation of Coulomb systems

Donko Zoltan
Molecular dynamics simulations of strongly-coupled plasmas

Z. Donko
Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences. H1121 Budapest, Konkoly-Thege Miklos str. 29-33. Hungary

Computer simulation methods represent a complementary approach to experimental and theoretical studies and they have become invaluable tools for the description of many-particle systems in numerous disciplines of science. In particular, the understanding of the physics of strongly-coupled (complex) plasmas has been aided remarkably by computational studies. One of the main and widely applied approaches is the molecular dynamics (MD) simulation, which makes it possible to trace the phase-space trajectories of particles thereby providing information about the time-evolution of the systems investigated. From the phase-space coordinates of the particles it possible to obtain static and thermodynamic properties (e.g. pair distribution and static structure functions, energy, pressure and compressibility), as well as dynamical characteristics of the systems. These latter comprise transport properties, phase transitions, and collective excitations (which can be investigated via the dynamical structure function and from current-current correlation functions).
The talk will cover the basics of equilibrium and non-equilibrium MD simulation methods and a review of recent accomplishments of MD simulation studies in the field of strongly-coupled plasmas. The topics to be covered are collective excitations of three-dimensional and two-dimensional Coulomb and Yukawa liquids [1], transport [2] and relaxation [3] phenomena, bilayers [4], and dipole liquids. The MD simulation results are compared to theoretical predictions (largely based on the quasi-localized charge approximation) and to experimental observations, when available.

[1] G. J. Kalman, P. Hartmann, Z. Donko, K. Kutasi, M. Rosenberg, Phys. Rev. Lett. 92, 065001 (2004); Z. Donko, G. J. Kalman, P. Hartmann, "Dynamical correlations and collective excitations of Yukawa liquids", in preparation for J. Phys. Cond. Matter.
[2] Bin Liu, J. Goree, O. S. Vaulina, Phys. Rev. Lett. 96, 015005 (2006); Z. Donko, J. Goree, P. Hartmann, K. Kutasi, Phys. Rev. Lett. 96, 145003 (2006).
[3] M. S. Murillo, Phys. Rev. Lett. 96, 165001 (2006).
[4] G. J. Kalman, P. Hartmann, Z. Donko, K. I. Golden, Phys. Rev. Lett. 98, 236801 (2007).

Streitz Fred
Particle Simulations of Hot Dense Matter with Radiation

F.H. Streitz, F.R. Graziani, R.M. More, M.S. Murillo, M.P. Surh, L.X. Benedict, S.P Hau-Riege, A.B. Langdon and R.A. London
Lawrence Livermore National Laboratory, U.S.A.

The variety of complex processes that take place in hot dense radiative plasmas where temperatures are in excess of several keV and densities are higher than metals, has forced computational physicists in ICF and astrophysics to make a number of assumptions regarding how to model non-equilibrium plasmas undergoing thermal relaxation. In order to make the simulations feasible, variations on the Landau-Spitzer model are frequently invoked. There has been recent work on the theoretical properties of thermal relaxation in such plasmas, but there is controversy due to the various approximations needed to make the calculations tractable. Experimental validations in the regimes of interest are prohibitive. Direct Numerical Simulation (DNS) of the many-body interactions of plasmas is a promising approach to model validation but unfortunately, previous work either relies on the collisionless approximation or radiation is entirely absent. We present a new numerical simulation capability that will address a currently unsolved problem: the extension of molecular dynamics to collisional plasmas where Brehmstrahlung and Compton scattering are present. This new tool provides a method for assessing the accuracy of energy and momentum exchange models in hot dense plasmas.
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was funded by the Laboratory Directed Research and Development Program at LLNL under project tracking code 07-ERD-044.

Ballenegger Vincent

Thermodynamics of Hydrogen at Low Densities: Screened Cluster Theory versus Quantum Monte Carlo Simulations

A. Alastuey (1) and V. Ballenegger (2)

(1) Laboratoire de Physique, Université de Lyon, ENS Lyon, CNRS, 46 allée d'Italie, 69364 Lyon

(2) Institut UTINAM, Université de Franche-Comté, CNRS, 16, route de Gray, 25030 Besancon

Hydrogen is known to display three different states at low densities: molecular, atomic, or ionized. The corresponding ionization and recombination equilibria are given, at a phenomenological level, by mass-action laws for ideal mixtures. Deriving corrections to those simple chemical approaches is notoriously difficult, because many effects come into play: formation and thermal excitations of atoms H, molecules H_2, ions H_2^+, H^-, thermal and pressure ionization, screening effects, interactions between atoms, molecules and ionized particles, etc. A proper description of such effects requires the introduction of the physical picture, namely quantum point protons and electrons which interact through the Coulomb potential. The screened cluster expansion (SCE) has been constructed within that framework [1]. It provides well-defined internal partition functions for any recombined entity thanks to screening. All aforementioned contributions are clearly identified in the corresponding diagrammatics. Thus, SCE turns out to be a useful tool for going beyond chemical approaches.

A first application of SCE is the derivation of systematic corrections to ideal Saha theory of atomic ionization, which has been proved to be exact in some scaling limit where both temperature and density vanish. The contributions of all above effects are properly ordered in that scaling limit [2]. Numerical comparisons of our analytical results for pressure and internal energy with quantum Monte Carlo simulations [3] show excellent agreement, even at rather high densities and temperatures (rs = 10, T = 15000 K).

As a second application of SCE, we propose a semi-phenomenological equation of state which describes the molecular recombination regime by retaining a few appropriate graphs. Simple numerical modelizations of the various contributions provide satisfactory results, as shown by comparisons with quantum Monte Carlo simulations [3].

[1] A. Alastuey, V. Ballenegger, F. Cornu and Ph. A. Martin, J. Stat. Phys. 113, 455 (2003).
[2] A. Alastuey, V. Ballenegger, F. Cornu and Ph. A. Martin, J. Stat. Phys. 130, 1119 (2008).
[3] B. Militzer and D. Ceperley, Phys. Rev. E 63, 066404 (2001).

Norman Genri

Fluctuation approach in the theory of strongly coupled plasmas

Genri E. Norman

Join Institute for High Temperatures of RAS Izhorskaya 13, bldg 2, Moscow 125412, Russia

The self-consistent joint description of free and weekly bound electron states in strongly coupled plasmas is presented. The fluctuation approach is developed to study the quasiclassical spectrum domain intermediate between low-lying excited atoms and free electron continuous energy levels. The molecular dynamics method is applied to study the model since the method is able to distinguish all kinds of fluctuations. The diagnostics of pair electron-ion fluctuations is developed. The concept of pair fluctuations elucidates the smooth vanishing of atomic states near the ionization limit. The approach suggested removes the artificial break of the electron state density at the ionization limit: atomic state density divergent at the negative energy side (–0) and free electron state density starting from zero density at the positive energy side (+0). The smooth restriction of pair fluctuation density is obtained which could explain the restriction of excited atom contribution to the atomic partition sum. The energy domain adjoining to the ionization limit is found out where the pair fluctuation density is close to zero, contrary to the Coulomb, Debye and Plank-Larkin approximations for the excited atom density, whereas the modeling results are close to the other approximations for the greater binding energies. Both density and appearance rate of pair fluctuations have maxima at nonidealities of 0.6-0.8. The distribution of pair fluctuations over lifetime is calculated, the exponential decay points to the random and independent character of pair production and destruction. The pair fluctuation average lifetime decreases monotonously with the increase of nonideality. The smooth transition from pair fluctuations to excited atoms is analyzed; the energy border between them is defined by the Stark broadening. The area of plasma nonidealities is discovered where there are neither excited atoms nor pair fluctuations. Indication is found out to the existence of minimum of electron state density in the domain intermediate between low-lying excited atoms and free electron states; it could be treated as a manifestation of a soft gap in the electron energy spectrum. Energy distribution of free electrons turns out to be Maxwellian and non-shifted with respect to the ionization limit of the isolated atom.

Ebeling Werner
The influence of Pauli blocking effects on theMott transition in dense plasmas

D. Blaschke, W. Ebeling, R. Redmer, H. Reinholz, G. Roepke
University Rostock, Institute of Physics, Humboldt University Berlin, Institute of Physics

We investigate the effects of Pauli blocking on the properties of plasmas at high pressures. In this region recent experiments have shown a transition from insulating behavior to metal-like conductivity. In order to describe this transition, several effects have to be taken into account of which one is the quantum character including the degeneration of the electrons. Since occupied electron states can only be occupied once (Pauli blocking), atomic states need more phase space than available at high densities and bound states disappear subsequently (Mott effect). We calculate the energy shifts due to Pauli blocking and discuss the Mott effect solving an effective Schrodinger equation for strongly correlated systems. The ionization equilibrium is treated on the basis of an advanced chemical approach based on the assumption that the system is a gas mixture of chemical species. We calculate the Pauli shifts by variational methods and discuss corrections due to polarization. Results for the ionization equilibrium in the region $5000K < T < 15000K$, $0.1 < \rho < 1$ g/cm^3 are presented where the transition from a neutral hydrogen gas to a highly ionized plasma takes place. We show that the transition to a highly conducting state is in the new approach softer than given within a first order approximation obtained in an earlier work.

[1] W.-D. Kraeft, D. Kremp, W. Ebeling, G. Roepke, Quantum Statistics of Charged Particle Systems, Berlin 1986.
[2] M. Mochalov, Lecture at the Conf. Strongly Coupled Coulomb Systems, Moscow 2005.
[3] V. Fortov, M. Mochalov et al., Phys. Rev. Lett. 99, 185001 (2007).
[4] D. Beule, W. Ebeling, A. Forster, H. Juranek, S. Nagel, R. Redmer, and G. Roepke, Phys. Rev. B 59, 14-177 (1999).
[5] W. Ebeling, H. Hache, H. Juranek, R. Redmer, G. Roepke, Contr. Plasma Phys. 45, 160 (2005).

Kalman Gabor
Perturbation Approach to Strong Coupling Plasma Properties

G. J. Kalman (1), I. M. Tkachenko (2), and K. I. Golden (3)
(1) Dept. of Physics, Boston College, Chestnut Hill, MA 02467, USA, (2) Dept. of Applied Mathematics, Polytechnic University of Valencia, Spain, (3) Dept. of Mathematics and Statistics, College of Engineering and Mathematical Sciences, University of Vermont, Burlington, VT 05401-1455, USA.

Studies of the dynamical properties of strongly coupled plasmas have been carried out through a variety of non-perturbative methods, primarily through the Quasi-Localized Charge Approximation (QLCA) and Molecular Dynamics (MD) simulations. These analyses predict behaviors that are qualitatively different from those of weakly coupled systems. The most interesting findings pertain to the collective excitation spectra of multicomponent systems, such as bilayers [1, 2] and binary mixtures of charged particles. In the strongly coupled liquid phases of these systems gapped (optic) longitudinal modes emerge [3, 4] that are absent in the RPA (Vlasov) description of the weakly coupled phases.
It is of great importance to determine whether these features are already nascent in a weakly coupled system, once correlational effects are accounted for, or, alternatively, some critical value of the coupling is required for them to appear. To find the answer to this question, we have applied an exact perturbation theoretic approach derived from the small γ (coupling parameter) expansion of the BBGKY hierarchy [5] to the calculation of the lowest order correlational correction to the dielectric response matrix (in species space) $\epsilon_{AB}(\mathbf{k},\omega)$. Analysis of the long wavelength behavior of $\epsilon_{AB}(\mathbf{k},\omega)$ reveals a new "out-of-phase" $O(\gamma)$ solution of the dispersion relation, with an $\omega(k)\to 0 > 0$ optic frequency, both in the bilayer and in the binary mixture. We attempt to connect these results with the gap frequencies found through the QLCA analysis. We also find that these modes are damped: since the QLCA does not provide a description of the damping, the study of the damping rate affords some further insight into the structure of these excitations. While the perturbation scheme that we have used is exact, some approximations in the course of the calculation were necessary: [5]. We try to assess the consequences of these approximations.
Supported by Grants from NSF, the Spanish Ministry of Education and Culture and INTAS.

[1] G. Kalman, V. Valtchinov and K. I. Golden, Phys. Rev. Lett. **82** 3124 (1999).
[2] Z. Donko, G. J. Kalman, P. Hartmann, K. I. Golden and K. Kutasi, Phys. Rev. Lett. **90** 226804 (2003).
[3] G. J. Kalman, D. Ballester, Z. Donko, P. Hartmann, unpublished.
[4] G. Kalman and K. I. Golden, Phys. Rev. A **41** 5516 (1990).
[5] H. Zhang and G. Kalman, Phys. Rev. A **45** 593 (1992)

Theory and simulation of Coulomb systems - Posters

Arkhipov Yuriy

Dynamic Local Field Correction and the Nevanlinna Parameter of the Theory of Moments in one-component Plasmas

Yu. V. Arkhipov (1), A. Askaruly (1), A. Ashikbaeva (1), A.E. Davletov (1), A. Imankulieva (1), G. Meirkanova (1), and I.M. Tkachenko (2)

(1) Department of Plasma Physics and Optics, Kazakh National University, Almaty, Kazakhstan, (2) Department of Applied Mathematics, Polytechnic University of Valencia, Valencia Spain

The dynamic local field correction (DLFC), $G(k,\omega)$, [1] plays an important role in the analysis of dynamic processes in strongly coupled plasmas. The aim of the present work is to obtain a closed expression for the DLFC in dense one-component plasmas within the method of moments based on sum rules and other exact relations, precisely, in terms of the Nevanlinna class parameter function [2]; analysis of its asymptotic properties, and the determination of the plasma collective modes dispersion relations. The Nevanlinna formula employed in the theory of moments [2] permits to find an explicit expression for the dielectric function in terms of the phenomenologically unknown Nevanlinna parameter function; a direct comparison of this expression with that of [1] provides a relation between the DLFC and the Nevanlinna parameter function, $Q(k,\omega)$: $G(k,\omega) = A + \Delta/(1+\omega/Q)$,(1) where $A = 1/\phi(k)\Pi(k,\omega) + (\omega^2 - \omega_2^2 + \omega_p^2)/(\omega_p^2)$, $\Delta = (\omega_2^2 - \omega_1^2)/(\omega_p^2) \geq 0, \phi(k) = (4\pi e^2)/k^2$ is the Fourier transform of the Coulomb potential, $\Pi(k,\omega)$ is the polarization operator in the random-phase approximation, ω_p is the plasma frequency, and ω_2 and ω_1 are the characteristic frequencies calculated within the method of moments [2, 3]. If we approximate the Nevanlinna parameter function by its static value, $Q(k,\omega) = i/\tau$, the DLFC will take the following form: $G(k,\omega) = ((A+\Delta) - iA\omega\tau)/(1 - i\omega\tau)$,(2) τ being the relaxation time; the form of eq. (2) coincides with that of [1]. Further, using eq. (2) and the definition of the dielectric function [1], the dispersion relation for Langmuir waves in strongly coupled plasmas was calculated.

[1] S. Ichimaru, Statistical plasma physics, vol. 2: Condensed plasmas, Westview Press, Boulder, 2004.
[2]V. M. Adamyan and I. M. Tkachenko, "Dielectric conductivity of non-ideal plasmas", Lectures on physics of non-ideal plasmas, part I, Odessa State University, Odessa, 1988, in Russian; V. M. Adamyan and I. M. Tkachenko, Contrib. Plasma Phys., 43, 252 (2003).
[3] Yu.V. Arkhipov et al., Vestnik KazNU, Ser. Physics, 2, 2008.

Baimbetov Fazylkhan
Ionization cross section of partially ionized hydrogen plasma. Variable phase approach.

F.B. Baimbetov (1), Z.A. Kudyshev (1)
Department of Physics, al – Farabi Kazakh National University, Almaty, Kazakhstan.

In represented work the electron impact ionization cross section is considered. The electron impact ionization cross section is calculated with help of variable phase approach to potential scattering. The Calogero equation is numerically solved [1], based on pseudopotential model of interaction between partially ionized hydrogen plasma particles, which accounts correlation effects [2]. As a result, the scattering phase shifts are obtained. On the basis of the scattering phase shifts, the ionization cross section is calculated [3]. It is compared with suitable results of calculations, represented in [4], [5], [6] and corresponding cross sections of classical Thompson [7] and Gryzinski [8] models. The results of calculations are in a good agreement with experimental data [9].

[1] F. Calogero, Variable phase approach to potential scattering, Academic Press, 1967.
[2] Baimbetov F.B., Arkhipov Yu.V., Davletov A.E., Thermodynamics of partially ionized hydrogen plasmas: Pseudopotential approach in chemical models. Phys. Plasma 2005, v.5, p. 315-321.
[3] A. S. Davidov, Quantum mechanics, ≪Nauka≫. – 1973. p. 536 – 550.
[4] Y.-K. Kim and M.E. Rudd, Phys. Rev. A 50, 3954 (1994).
[5] M. B. Shah, D. S. Elliott, and H. B. Gilbody, J. Phys B 20, 3501 (1987)
[6] S. M. Younger, J. Quant. Spectrosc. Radiat. Transfer 26, 329 (1981).
[7] J.J. Thompson, Phil. Mag. 23, 449 (1912)
[8] M. Gryzinski, Phys. Rev. 138, A336 (1965).
[9] N. Mott and H Massey, The Theory of Atomic Collisions.

Boehm Helga
Double-Plasmon Excitations in the Alkali Metals

Helga M. Böhm, Robert Holler, Eckhard Krotscheck, Martin Panholzer
Institute of Theoretical Physics, Johannes Kepler University, Altenbergerstr. 69, A-4040 Linz, Austria

We calculate the excitation spectrum of the electron liquid using the formalism of Correlated Basis Functions (CBF). By including *time–dependent* pair correlations we are able to account for dynamic pair excitations in the density–density response function. In addition, the treatment of static correlations is also improved by using a suitable effective interaction from an optimized ground state. This approach was originally developed for ^{4}He; its application to the charged boson fluid showed [1] that both static and dynamic correlations provide major mechanisms for lowering the plasmon energy. Here we study the much more demanding fermionic case.
Recent inelastic X–ray scattering (IXS) measurements [2] on Al have revealed a shoulder on the high energy side of the dynamic structure factor $S(q, \omega)$ that was identified as a correlation–induced ("intrinsic") double–plasmon excitation. Our formalism is naturally suited for studying this type of excitations: The frequency dependence of the dynamic effective interaction in the density response function is governed by a "two–particle Lindhard function" taken at collective pair excitations [3]. For Al we find a dynamic structure factor generally consistent with the experiments, but with a different double–plasmon dispersion. Here we present predictions for the series of the alkali metals, with special emphasis being put on the dispersion of both the single– and the double–plasmon.

[1] V. Apaja, J. Halinen, V. Halonen, E. Krotscheck and M. Saarela, Phys. Rev. B **55**, 12925 (1997).
[2] C. Sternemann, S. Huotari, G. Vankó, M. Volmer, G. Monaco, A. Gusarov, H. L. K. Sturm and W. Schülke, Phys. Rev. Lett. **95**, 157401 (2005).
[3] H. M. Böhm, R. Holler, E. Krotscheck, and M. Panholzer, to be published in Int. J. Mod. Phys. B, (2008).

Bonitz Michael
Coulomb scattering in strong laser fields

Sebastian Bauch and Michael Bonitz
Institut für Theoretische Physik und Astrophysik. Christian-Albrechts-Universität zu Kiel

Generating fast electrons from table top sources powered by strong laser systems is becoming an interesting tool for experimentalists. In most cases the effect of the wake field acceleration is used [1]. Also femtosecond and sub-femtosecond processes triggered by short pulse lasers become of interest since they promise to study chemical reaction or photoemission processes with unprecendented time resolution [2]. In our present work we show an alternative way to generate distributions of high-energy electrons by scattering of electrons on a few ions in the presence of a strong accelerating laser fields. Here the main processes take place on the nanometer scale. This gives rise to strong Coulomb correlations an highly nonlinear scattering effects. We solve the multi-dimensional time-dependent Schrödinger equation on large spatial grids and show how electron wave packet scattering on Coulomb-like potentials (ions) in strong laser fields leads to resonance phenomena and distributions of fast electrons. In previous works [3] only one-dimensional systems were studied. We now demonstrate that carefully chosen scattering geometries and additional external electric fields allow to extend these results to realistic setups. In order to make predictions the angle-resolved energy spectrum is analyzed [4].

[1] Th. Katsouleas, Nature 341, 516 (2004).
[2] E.E. Krasovskii, and M. Bonitz, Phys. Rev. Lett. 99, 247601 (2007).
[3] H.J. Kull and V.T. Tikhonchuk, Phys. Plas 12, 063301 (2005).
[4] S. Bauch, and M. Bonitz, submitted for publication.

Casula Michele
Phase diagram of two dimensional Boltzmannons with long-range interactions.

Department of Physics, University of Illinois at Urbana-Champaign 1110, W. Green St. Urbana, IL 61801, USA
Bryan K. Clark, Michele Casula, and David M. Ceperley

We investigate the phase diagram of a two dimensional quantum gas obeying Boltzmann statistics and interacting with a long-range 1/r potential. This model is relevant to study the liquid-to-crystal transition in two dimensions driven by Coulomb interactions. The interplay between reduced dimensionality and long-range potential can lead to peculiar properties, such as Pomeranchuk effect, hexatic and microemulsion phases. By performing path integral and diffusion Monte Carlo simulations, we explore the finite temperature and ground state properties of the system, by studying the onset of translational and orientational orders. We discuss the results for this model in relation with the physics of the two dimensional electron gas.

Daligault Jerome

Classical Ion Dynamics in Liquid Metal and Dense Matter beyond the Born-Oppenheimer Approximation.

Jerome Daligault
Theoretical Division MS-K717, Los Alamos National Laboratory, Los Alamos, NM 87545

The dynamics of interacting electrons and ions in electron-ion systems such as liquid metals or dense plasmas is usually treated within the Born-Oppenheimer or adiabatic approximation, in which electrons are assumed to remain in the ground state of the instantaneous ionic configurations as the ions move. The adiabatic approximation, which is an excellent approximation for many purposes such as the calculation of equations of states and of the electronic conductivity, is questionable when one deals with non-equilibrium conditions in which the dynamical electron-ion coupling effects may be important. Typical examples include phase transitions occuring under far-from equilibrium conditions in laser-matter, shock wave and radiation damage experiments. Another situation is the return to equilibrium of two-temperature plasmas created when energy is deposited into matter. Recently [1,2], we rigorously derived the equation of motion for the clasical ions of equilibrium and non-equilibrium electron-ion systems in the quantum-mechanical environment of the electron. Ions follow a (generalized) Langevin equation whose stochastic nature reflects the fluctuations in the forces that the electrons exert on the ions and that are responsible for the disspation of energy between the two subsystems. The equation tells one how to include, beyond the adiabatic approximation, the electronic thermal and quantal fluctuations in the dynamics of ions in non-equilibrium matter. We could also use the ionic equation of motion to derive a general expression for the energy relaxation rates in two-temperature plasmas, which we applied to warm dense matter. In this talk, I will discuss our approach and the numerous implications of our results.

[1] J. Daligault and D. Mozyrsky, "Ion dynamics and energy relaxation rates in nonequilibrium electron-ion systems", Phys. Rev. E 75, 026402 (2007).
[2] J. Daligault and D. Mozyrsky, "Effect of the liquid-like ionic structure on the electron-ion energy relaxation timescales in dense plasmas", High Energy Density Physics 4, 58 (2008).

Di Caprio Dung
Simple field theoretical approach of Coulomb systems. Entropic effects.

D. di Caprio (1), M. Holovko (2)
(1) University Paris 6, CNRS, 4, Pl. Jussieu 75005 Paris, France. (2) Institute for Condensed Matter Physics, 1 Svientsitskii Str., 79011 Lviv, Ukraine.

We consider a field theory approach of the liquid state. The Hamiltonian includes the standard interaction as for particles, however the specificity lies in the entropic term which substitutes for the fields the combinatorial coefficients needed for indiscernable particles. This entropic term introduces new perspectives in the interpretation of different physical problems.
Rather simple and intuitive the theory is exact. The relation with the standard statistical mechanics has been discussed [1]. The exact so-called contact theorem has been derived emphasizing in this framework the role of the entropic functional [2].
The role of the combinatorial entropy can be illustrated and emphasized in the case of ionic systems. Their interest is that having at least two ionic species one can discuss non trivial combinatory. For an ionic system at an interface, the approach gives a simple interpretation of the so-called anomalous behaviour of the electric capacitance with the temperature. Within a basic point ion model, we show that an entropic coupling between the total density and the charge field is important. Then the hard sphere volume exclusion appears as a correction [3]. The generalisation to asymmetric in valence electrolytes further illustrates that the approach is able to capture the main features of these systems where the ionic concentration balance is for each system modified in order to satisfy the electroneutrality condition [4].
Finally, we discuss criticality for these asymmetric in valence ionic systems. The predictions for the critical point exhibit both the decrease of the critical temperature as well as the increase of the critical density [5]. We first discuss a point ion based model emphasizing the role of the combinatory entropy showing that the main effects can be found for such a simple model. Then we introduce the hard sphere volume exclusion in order to obtain quantitative results.

[1] D. di Caprio, J.P. Badiali, J. Phys. A Math. Gen. 41, 125401 (2008).
[2] D. di Caprio, J.P. Badiali, J. Stafiej, Mol. Phys. 104, 3443 (2006).
[3] D. di Caprio, M. Valisko, M. Holovko, D. Boda, J. Phys. Chem. C, 111, 15700 (2007).
[4] D. di Caprio, M. Valisko, M. Holovko, D. Boda, Mol. Phys. 104, 3777 (2006).
[5] M.E. Fisher, J.N. Aqua, S. Banerjee, Phys. Rev. Lett. 95, 135701 (2005).

Dufty James
Kinetic Theory for Fluctuations of Confined Charges

James W. Dufty and Jeffrey Wrighton
Department of Physics, University of Florida, Gainesville, FL 32611, USA

The dynamics of fluctuations for charges near a positive ion or in a confining potential is considered. A semi-classical description using regularized quantum potentials is applied to obtain a formally exact linear kinetic theory. The generator for the dynamics is approximated by its exact form in the short time limit. The resulting Markov kinetic equation is solved in terms of an effective mean field single particle dynamics and dynamical screening by in an inhomogeneous electron gas RPA with "local field corrections". Practical applications are illustrated by calculating the dependence of the electric field autocorrelation function on the ion charge number, and on bound and free electron configurations. The results here generalize recent studies [1,2] to strong electron coupling and a wide range of correlation functions.

[1] J. W. Dufty, I. Pogorelov, B. Talin, and A. Calisti, J. Phys. A 36, 6057-6062 (2003).
[2] B. Talin, A. Calisti, J. Dufty, and I. Pogorelov, Phys. Rev. E 77, 036410 (2008); cond-mat/0402023; cond-mat 0210713.

Filinov Vladimir
Tomography represetaion of quantum dymanics

V.S. Filinov (1,2), G. Schubert (3), P. Levashov (1), H. Fehske (3), M. Bonitz (2), V. Fortov (1)
(1)Joint Institute for High Temperatures, Russian Academy of Sciences, Izhorskaya 13/19, Moscow 127412, Russia, (2)Christian-Albrechts-Universität zu Kiel, Institut für Theoretische Physik und Astrophysik, Leibnizstrasse 15, 24098 Kiel, Germany, (3)Institut für Physik, Ernst-Moritz-Arndt-Universität Greifswald, Domstrasse 10a, D-17489 Greifswald, Germany

The probability representations or tomography representation of quantum mechanics was recently proposed in terms of marginal distribution functions (MDF). MDF describing the quantum states are positive distribution functions connected with wave functions or density matrices by known integral transformation. Sign conservation of the of the MDF can be valuable in computer simulations to overcome the "sign problem". To obtain evolution of MDF we developed new stochastic approach to solution of the generalized Langevin equation (GLE). GLE is derived from Kolmogorov equations for Green function of evolution equation for MDF. We discuss the basic relations and main ideas of this approach, compare obtained numerical results with results of independent finite-difference calculations for quantum oscillator and quantum particles crossing the finite well and tunneling through the gaussian barrier.

Gericke Dirk O.
Coupled Mode Effects on Temperature Relaxation

D.O. Gericke (1), J. Vorberger (1) and G. Gregori (2)
(1) Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom, (2) Clarendon Laboratory, Department of Physics, University of Oxford, Oxford OX1 3PU, United Kingdom.

The equilibration of electron and ion temperatures is the latest relaxation stage before local equilibrium is achieved. It thus determines the minimum time delay in pulse-probe measurements of equilibrium properties of dense plasmas. The energy transfer between electrons and ions is mainly governed by binary collisions which can, however, be modified or partially prohibited by the surrounding plasma. Thus the relaxation process itself is well-suited to investigate dense plasma effects such as screening, strong coupling in the ion component, strong electron-ion collisions, collective modes and electron degeneracy. From an experimental point of view, temperature relaxation is also very interesting since it occurs, for solid densities, on a pico-second time scale that can nowadays be resolved.
In this contribution, we discuss the influence of collective excitations on the electron-ion energy transfer; in particular, modes in a fully coupled electron-ion system. We start considering weakly coupled plasma with well-known modes and a nonequilibrium description based on the Lenard-Balecu equation. It is shown that a coupled mode formula equivalent to the one by Dharma-wardana & Perrot follows. Then we will follow two different routes to evaluate this formula: first, we demonstrate how a direct numerical evaluation can be performed. Then we show an attempt to derive a simplified version of this energy transfer equation which is based on a plasmon pole-like approximation for the dielectric function. This known form allows then for an analytical solution which gives a corrected Spitzer formula.
Both approaches give considerably reduced energy transfer rates even for weakly coupled plasmas (about a factor of two) if, and only if, ion acoustic modes are present in the plasma. This is particularly interesting for very high electron temperatures where the Spitzer formulation is (incorrectly) believed to be valid. Both approaches can also be easily extended to include strong coupling effects by local field corrections for the direct evaluation and by a different mode structure for the reduced model. Depending on the plasma conditions, the resulting rates can be even more reduced yielding an order of magnitude corrections to the Spitzer/Brysk results.

Golyatina Rusudan
Modeling of plasmas structure near electrode layer with magnetic field

R.I. Golyatina, A.S Maiorov
A.M. Prokhorov General Physics Institute of RAS, Moscow, Russia

In the paper [1] it was shown that discharge in the mixture of light and heavy gas leads to the appearance of special features in the velocity distribution of ions. Important element of physical influence on the dust plasma is imposition of external magnetic field. Investigating dust structures and taking into account this factors it was worked out the model for the simulation of discharge in gas mixture with external magnetic field. There were considered two geometrical cases: plane near electrode layer and the axisymmetric case, in which all plasma characteristics depended on only the radius, and along axis were constant. To simulate of the charge transport in the gas discharge we took into account the electrons and ions birth and recombination, their transport in weakly ionizated gas. Electrons birth and death on the walls were considered for the electron transport model of elastic collisions. For ions we took into account the elastic collisions, polarized collisions and collisions with resonance charge exchange [2]. The external magnetic field was assumed to be constant. The results of numerical simulation made it possible to obtain the following characteristics for the plane layer: the ion and electron densities, electric field, the velocity and angular distribution of ions. The following characteristics were calculated for the axisymmetric case (gas-discharge tube): the electron and ion densities, radial electric field in dependence on the radius (distance from tube axes), the velocity distribution of ions, the mean kinetic energy of ions, ion and electron currents. This program was being used for the calculation of the gas discharge characteristics in experiments with dust plasmas and in case of the cryogenic temperatures of the gas [3], in the mixtures of noble gases (He-Ar, He-Kr) and in the presence of the magnetic field [4].

[1] S.A. Maiorov Bulletin of the Lebedev Physics Institute, No 7 (2007).
[2] S.A. Maiorov Plas. Phys. Rep. 32, No 9, 737, (2006).
[3] S.N. Antipov, E.I. Asinovskii, A.V. Kirillin, et al., JETP, No. 4, (2008).
[4] M.M. Vasiliev, L.G. Dychkov, S.N. Antipov, et al., JETP Lett, 5-6, 414 (2007).

Grinenko Alon
Dynamic Conductivity of Dense Plasmas

A. Grinenko and D.O. Gericke
Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

The dynamical conductivity of dense plasmas is an important property for any hydrodynamic simulation of laser-matter interaction since it determines the energy deposition of the laser field into the material. Due to its relation to the dielectric fuction of the system, it also influences many other equilibrium and transport ptoperties. In dense, strongly coupled plasmas, electron-ion collisions as well as the ionic structure must be considered in a theoretical description which raises the problem of a correct description of the dynamically screened interactions.
Here, we develop an approach to determine the dynamic conductivity from a kinetic description of the electron distribution function and, accordingly, the screened potential in the presence of a laser field. In this approach, the energy deposition due to the collective mean-field excitation and local collisional absorption are treated simultaneously. The derivation follows the lines of the usual perturbation expansion of the distribution function about the equilibrium. That is, the electrons are Maxwell/Fermi distributed in a frame moving with their center of mass. The kinetic description must be transformed accordingly (see Ref. [1]). Here, different approximations for the collision integral (right hand side of the kinetic equation) are considered which allows to include strong electron-ion collisions and dynamic screening. The main extension to existing approaches is the selfconsistent determination of the screening function. Present approaches use either static Debye-like screening or dynamic screening in the zeroth order random phase approximation. Such a treatment introduces a degree of inconsistency when calculating dynamic collision frequencies. To avoid this, we iterate the proceedure using the dielectric properties obtained in the next order of approximation. After convergence this yields a selfconsistent dynamic conductivity and related collision frequency similar to the Mermin ansatz [2].

[1] J. Dawson and C. Oberman, Phys. Fluids, 5, 517 (1962).
[2] N. D. Mermin, Phys. Rev. B, 1, 2362 (1970).

Hartmann Peter
Collective excitations of electron-hole bilayer systems

Peter Hartmann (1), Alexey Filinov (2), Michael Bonitz (2) and Zoltán Donkó (1)
(1) Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, H-1525 Budapest, POB. 49, Hungary, (2) Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, D-24098 Kiel, Germany.

We report a series of quasi-classical molecular dynamics (QCMD) simulations on the wave-dispersion properties of electron–hole bilayer systems. Our aim is to incorporate quantum effects in an approximative way through effective pair interaction potentials $\Phi_{\rm Q}(r,n,T)$ which are both temperature and density dependent. To derive these effective potentials we use the path integral Monte Carlo (PIMC) method, which allows us to evaluate pair interaction energies as a function of interparticle distance.
While PIMC is limited to comparably small system sizes and makes it possible to derive static properties (e.g. $g(r)$ pair distribution functions, static structure factor) only, molecular dynamics simulations provide the possibility to study the real time-evolution of significantly larger systems, where collective excitations prevail. Hence, in our novel approach we aim to combine the advantages and extend the range of applicability of both methods.
In the present work we (i) apply PIMC simulations to a system of spatially separated layers of electrons and holes (e.g. indirect excitons in double quantum wells) [1], and (ii) extract $g(r)_{\rm PIMC}$ and effective pair-potentials $\Phi_{\rm Q}(r,n,T)$. (iii) Using $\Phi_{\rm Q}$ we apply QCMD simulations to calculate the $S(k,\omega)$ dynamical structure function and wave-dispersions of the four expected modes (L–longitudinal, T–transverse, with in-, and out-of-phase oscillations). To benchmark the applicability of our combined method we compare the pair-distribution functions $g(r)_{\rm PIMC}$ and $g(r)_{\rm QCMD}$.
The advantage of the present approach is shown in comparison with the QCMD simulations based on first-order perturbation effective potentials like Kelbg, improved-Kelbg [2], and the unscreened Coulomb interaction [3].

[1] Filinov A V, Bonitz M, Ludwig P, Lozovik Yu E, Phys. Stat. Sol. (c) **3**, 2457 (2006).
[2] Filinov A V, Golubnychiy V O, Bonitz M, Ebeling W, Dufty J W, Phys. Rev. E **70**, 046411 (2004).
[3] Kalman G J, Hartmann P, Donko Z, Golden K I, Phys. Rev. Lett. **98**, 236801 (2007)

Hartmann Peter
Higher harmonic generation in strongly coupled charged particle systems

Peter Hartmann (1), Zoltan Donko (1), Gabor J. Kalman (2), Kevin P. Tierney (2), Marlene Rosenberg (3) and Kenneth I. Golden (4)

(1) Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, H-1525 Budapest, POB. 49, Hungary, (2) Department of Physics Boston College,Chestnut Hill, Massachusetts 02467, USA, (3) Dept. of Electrical and Computer Engineering, University of California, San Diego, La Jolla, CA 92093-0407, (4) Dept. of Mathematics and Statistics, College of Engineering and Mathematical Sciences, University of Vermont, Burlington, VT 05401-1455 USA.

Over the past few decades considerable work has been devoted to the investigation of collective mode excitations in strongly coupled many-particle systems. The main interest has been focused on the wave dispersion properties in the plane-wave approximation (characterized by a single wavenumber and frequency for each mode). Experiments, computer simulations and theoretical approaches all successfully describe the nature of the fundamental excitations. Recent experiments [1,2] and computer simulations [3], have further identified the emergence of second, or even higher harmonics of certain frequencies of the fundamental excitations in the spectra of the equilibrium dynamical structure functions. An analytic description of harmonic generation of non-thermal excitations for 1D systems has been proposed by Avinash [4].

We report a summary of the second and higher harmonic generation in a wide variety of strongly coupled charged particle systems. Molecular dynamics simulations have been carried out for three-dimensional (3D) and two-dimensional (2D) Coulomb and Yukawa (screening parameter $\kappa = 0...3$) systems, as well as for unipolar (electronic) and bipolar (electron-hole) bilayers. Harmonic peaks have been identified both in the density- and in the current-fluctuation spectra. Conclusions based on our observations are: (i) the amplitude of the harmonic peaks are highest in the intermediate strongly-coupled liquid domain ($\Gamma/\Gamma_{\rm m} \approx 0.4$, where $\Gamma_{\rm m}$ is the Coulomb coupling parameter where melting happens); (ii) the strongest harmonic frequency is almost wavenumber independent and has approximately twice the frequency where the peak in the $g(\omega)$ frequency distribution occurs; the peak originates from the frequency "plateau" usually in the vicinity of the wavenumber $ka \approx 2$ (a is the Wigner-Seitz radius); (iii) in the case of the bilayers a selection rule seems to operate, creating even harmonics in the in-phase and odd harmonics in the out-of-phase mode only; (iv) the system where the strongest harmonic generation is observed is the bipolar bilayer.

We present tentative heuristic explanations of these qualitative observations.

[1] Nunomura Set et al., Phys. Rev. E **68**, 026407 (2003).
[2] Nosenko V et al., Phys. Rev. Lett. **92**, 085001 (2004).
[3] Kalman G J et al., Phys. Rev. Lett. **98**, 236801 (2007).
[4] Avinash K, Phys. of Plasmas **11**, 1891 (2004).

Holler Robert
Dynamic Pair Excitations in Two–Dimensional Fermi Fluids

Helga M. Böhm, Robert Holler, Eckhard Krotscheck, Martin Panholzer
Institute of Theoretical Physics, Johannes Kepler University, Altenbergerstr. 69, A-4040 Linz, Austria

In two–dimensional (2D) systems correlation effects are often more pronounced than in bulk systems, as the particles have fewer possibilites to screen the interaction and to "evade" into the third dimension. It is therefore worthwile to test the theory developed recently [1] for fermionic quantum fluids by applying it to layers of electrons or of ^{3}He atoms. Recent measurements of the dynamic structure function of 2D ^{3}He revealed a collective mode inside the particle–hole continuum [2]. This data cannot be explained by random phase approximation (RPA) related theories (invoking static effective interactions or static "local field corrections"). 2D electron systems in semiconductor hetero–structures and MOSFETS provide another important realization of 2D quantum fluids with an accurately measured collective mode [3].
First attempts [2] at calculating the response function of fermionic systems showed that our theory, which includes time–dependent pair correlations in the formalism of correlated basis functions, holds the potential for a quantitatively accurate description of the dispersion of the collective mode. The improved version of Ref. [1] also accounts for long wavelength damping due to pair excitations. Here we present results for the dynamic structure function of both, 2D ^{3}He and electrons, and compare the dispersion of the collective mode with experiments [2,3].

[1] H. M. Böhm, R. Holler, E. Krotscheck, and M. Panholzer, to be published in Int. J. Mod. Phys. B, (2008).
[2] H. M. Böhm, H. Godfrin, E. Krotscheck, H. J. Lauter, M. Meschke and M. Panholzer, Int. J. Mod. Phys. B 21, 2055 (2007).
[3] T. Inaoka, T. Nagao, S. Hasegawa, T. Hildebrandt, and M. Henzler, Phys. Rev. B 66, 245320 (2002).

Klymenko Valeriy
Competition of Coulomb, van der Waals, and magnetic dipole interactions in systems of reduced dimensionality

Valeriy E. Klymenko, Viktor M. Rozenbaum
Institute of Surface Chemistry, NAS Ukraine, Gen. Naumova Str. 17, Kiev, 03164, Ukraine

Manifold properties of a material are governed by the balance of various interactions between its structural units. In this context, systems of reduced dimensionality are most convenient objects to study the interplay of the forces involved. On the other hand, chain and planar structures are typical of supramolecular nanoassemblies and, furthermore, chains often represent the ground-state structures in systems with multipole interactions as, e.g., in monolayers of nonpolar molecules on dielectric substrates [1]. Theoretical treatment of such quasi-one-dimensional molecular arrays has revealed nontrivial orientational phases which result from competing quadrupole-quadrupole and van der Waals dipole-dipole interactions [2]. We have also analyzed the characteristics and peculiarities of the corresponding phase transitions controlled by intermolecular distances. The phase diagram obtained becomes more informative if magnetic dipole interactions are included, which is particularly significant in the consideration of oxygen molecules [3].

[1] V. M. Rozenbaum and S. H. Lin, Spectroscopy and Dynamics of Orientationally Structured Adsorbates (World Scientific, Singapore, 2002).
[2]. V. E. Klymenko and V. M. Rozenbaum, J. Chem. Phys. 110, 5978 (1999).
[3]. V. E. Klymenko and V. M. Rozenbaum, Mol. Phys. 101, 2855 (2003).

Kurilenkov Yuri

PIC simulations of inertial electrostatic confinement and DD microfusion at self-organized interelectrode media of nanosecond vacuum discharge.

Yu. K. Kurilenkov (1), M. Skowronek (2), V.P.Tarakanov (1) and J. Dufty (3)
(1) Joint Institute for High Temperatures of Russian Academy of Sciences, 13/19 Izhorskaya Str., 125412 Moscow, Russia, (2) Laboratoire des Plasmas Denses, Université Pierre et Marie. Curie, F-75252 Paris Cedex 05, France, (3) Department of Physics, University of Florida, Gainsville, FL 32611, USA

Earlier, generation of energetic ions and DD neutrons from microfusion at interelectrode space of low energy nanosecond vacuum discharge have been demonstrated [1]. In a limiting case of total trapping of fast deuterium ions by self-organized "dusty" cloud of clusters from anode material (under partial hard x-rays diffusion and multiple fusion events inside), the pulsating neutrons yield have maximum values $\sim 107/4pi$ per shot at ~ 1 J of total energy applied (table-top complex plasma "microreactor"[1]). Nevertheless, the physics of fusion processes and some results on neutron yield from database accumulated were understood poorly. At this work, the detailed PIC simulation of the discharge experimental conditions using fully electrodynamic code [2] are presented and discussed. The dynamics of all charge particles was reconstructed in time and space (extracted from cathode electron beams which are strongly correlated with accelerating deuterium ions). The principal role of virtual cathode (VC) and corresponding single and double potential wells formations at interelectrode space are recognised. The calculated depth of quasistationary potential well of VC is about 50-60 keV, and the D+ ions being trapped by this well are accelerating up to the same energy values that provides collisional DD nuclear synthesis. Ccorrelation between calculated potential well structures (and dynamics) and neutron yield observed is available and discussed. Underline, experiment [1] on miniature neutron source extends available activity on inertial electrostatic confinement fusion (IECF). In particular case, ions in the potential well undergo high frequency ($\sim$ 75 MHz) harmonic oscillations (accompanied by correspondent regime of oscillatory neutron yield [1]) which are similar to periodically oscillating plasma spheres conception [3]. Both experiment and PIC simulations illustrate very favourable scaling of fusion power density at particular IECF scheme chosen which increases with the inverse of the virtual cathode radius and square of potential well depth.

[1] Yu.K. Kurilenkov, M. Skowronek and J.Dufty, Journal of Physics A: Math. & General 39 (2006) 4375.
[2] V.P.Tarakanov, User's manuel for code KARAT (Springfield, VA: Berkley Research Associates, Inc., 1992).
[3] J. Park et al. Physics of Plasmas 12 (2005) 05631.

Lankin Alexander
Molecular dynamics modeling of collisional recombination in strongly coupled plasmas

Alexander Lankin
Alexander Lankin Joint Institute for High Temperatures of RAS Izhorskaya st. 13/19, Moscow 125412, Russia

The goal of this works is to study the rate of collisional recombination in non-equilibrium nondegenerate strongly coupled plasmas. The results are obtained by molecular dynamics (MD) simulations including the simulation technique to distinguish electron-ion pairs corresponding to the quasiclassical bound states [1,2].
Rate of recombination in ideal plasma can describe ratio $K_e = CZ^3e^{10}m^{-1/2}n_e^2n_iT^{-9/2}$ where coefficient C is independent from temperature and pressure of plasma. In strongly coupled plasmas the radio is not described rate of recombination on plasma. But it can describe rate of recombination if the coefficient C is considered as function of temperature and electron number density.
Dependences of rate of recombination on various plasma parameters such as nonideality, ion charge and distribution of particle in plasma are obtained. It is found that the coefficient C decrease monotonous with growth of nonideality of plasma. Moreover coefficient C decreases fast than power of -9/2 in strong nonideality plasma. As a result of the depending of rate collision recombination on nonideality is not monotonous. In small parameter of nonideality it increases according to the law of three body recombination on ideality plasma. But it has maximum on larger nonideality and rate of recombination decreases on strongly coupled plasmas. For plasma with charge of ion equal unity it locates on $\Gamma < 0.9$.
Rate of recombination depends from charge of ions much strong. For small nonideality the dependence agree with the law Z^3 as well as ideality plasma. But ratio of recombination rate in plasma with ion charge equal one and plasma with ion charge more then one decrease with growth of parameter of nonideality in strongly coupled plasmas fast.
Analytical dependence for rate of recombination from nonideality and charge of ion is obtained as $K_e = K_0Z^3\Gamma^{9/2}\exp(-a\Gamma)\exp(-bZ\Gamma)$ where the coefficients K, a, b are calculated from results of MD simulation.
In order to investigate influence of the form of the electron-ion interaction potential we choose the Coulomb potential with a cut-off at short distances. Various properties of the bound states are obtained depending on the depth of this potential $U_{min} = -(5-15)kT$. In this parameter rate of recombination is independent from depth of potential.

Marchi Mariapia
Effects of mass anisotropy, thickness and valley degeneracy on the spin susceptibility of the 2DEG in AlAs QWs

M.Marchi (1,2), S. De Palo (1,3), S. Moroni (1), G. Senatore (1,3)
(1) INFM-CNR-DEMOCRITOS National Simulation Center, Trieste, Italy, (2) International School for Advanced Studies (SISSA), via Beirut 2-4, 34014, Trieste Italy, (3) Dipartimento di Fisica Teorica, Università di Trieste, Strada costiera 11, 34014 Trieste, Italy

We present predictions of the spin susceptibility, obtained from extensive DMC simulations, for a two dimensional (2D) electron gas (EG) with mass anisotropy appropriate to AlAs QWs[1]. We consider both the strictly 2D limit and thicknesses encountered in actual devices[1], as well as one and two-valley systems. We demonstrate that in the one-valley case anisotropy suppresses the spin suscepibility substantially at all densities and in particular at those relevant to experiments[1], the effect being larger at lower density. This suppression adds onto the one due to thickness[2,1]. In the two-valley case we find an interesting interplay of the anisotropy and the valley degree of freedom in determining the EG properties and in particular the spin susceptibility. We find a very good agreement between our predictions and the available experimental evidence[1], pointing to a minor residual role of disorder on the spin susceptibility at low density in the one-valley devices[1].

[1] O. Gunawan et al., Phys. Rev. Lett. 97, 186404 (2006); T. Gokmen et. al., Phys. Rev. B 76, 233301 (2007), and references therein.
[2] S. De Palo et. al., Phys. Rev. Lett. 94, 226405 (2005); ibidem, 97, 39702 (2006), and to be published.

Mayorov Sergey
Coulomb microfield distribution in an ion cluster

S.A. Maiorov(1), A.A. Shcherbakov(2)
(1) General Physics Institute of the Russian Academy of Science, Moscow, Russia (2) Moscow Institute of Physics and Technology, Dolgoprudny, Russia

When dealing with systems of charged particles their field is often regarded as microfield for the purpose of distinguishing it from internal fields. Distribution of such microfields in the dependence of system under consideration can determine various properties related to this system such as atoms spectra shifts and broadening, particles cross sections and others. Therefore a knowledge of typical behavior of microfields distribution (asymptotic, extrema) for particular systems can turn to be useful for analysis of different physical phenomena that take place there. The question of finding of this function becomes urgent while studying for example interaction processes between high-power laser pulse and clusters of atoms. These clusters can contain from dozens to thousands of atoms or molecules [1]. During interaction the cluster molecules ionize and electrons fly away for the time about 10-100 fs [1]. In the dependence of the cluster size can be ionized as all atoms as only part of them. Because the fly-off time of ions is usually larger by 1-3 orders of magnitude than the corresponding time for the electrons there is a point in talking about inertial confinement of compact systems of charged particles described above. Using the molecular dynamics and Monte-Carlo technique we studied the microfield distribution in clusters. The obtained results were compared with corresponding distributions in unbounded plasma [2-6] and it is shown that calculated distributions have the same asymptotic (this result contradicts with [7]). The localization of the maximum and auxiliary exptrema presence depends on the cluster size. We also investigated the dependence of microfield mathematical expectation and dispersion from the number of particles in cluster. Microfield distributions projections on an arbitrary axis are demonstrated.

Mayorov Sergey
Modeling of plasmas structure near electrode layer with magnetic field

R.I. Golyatina, A.S Maiorov
A.M. Prokhorov General Physics Institute of RAS, Moscow, Russia

In the paper [1] it was shown that discharge in the mixture of light and heavy gas leads to the appearance of special features in the velocity distribution of ions. Important element of physical influence on the dust plasma is imposition of external magnetic field. Investigating dust structures and taking into account this factors it was worked out the model for the simulation of discharge in gas mixture with external magnetic field. There were considered two geometrical cases: plane near electrode layer and the axisymmetric case, in which all plasma characteristics depended on only the radius, and along axis were constant. To simulate of the charge transport in the gas discharge we took into account the electrons and ions birth and recombination, their transport in weakly ionizated gas. Electrons birth and death on the walls were considered for the electron transport model of elastic collisions. For ions we took into account the elastic collisions, polarized collisions and collisions with resonance charge exchange [2]. The external magnetic field was assumed to be constant. The results of numerical simulation made it possible to obtain the following characteristics for the plane layer: the ion and electron densities, electric field, the velocity and angular distribution of ions. The following characteristics were calculated for the axisymmetric case (gas-discharge tube): the electron and ion densities, radial electric field in dependence on the radius (distance from tube axes), the velocity distribution of ions, the mean kinetic energy of ions, ion and electron currents. This program was being used for the calculation of the gas discharge characteristics in experiments with dust plasmas and in case of the cryogenic temperatures of the gas [3], in the mixtures of noble gases (He-Ar, He-Kr) and in the presence of the magnetic field [4].

[1] S.A. Maiorov Bulletin of the Lebedev Physics Institute, No 7(2007).
[2] S.A. Maiorov Plas. Phys. Rep. 32, No 9, 737, (2006).
[3] S.N. Antipov, E.I. Asinovskii, A.V. Kirillin, et al., JETP, No. 4, (2008).
[4] M.M. Vasiliev, L.G. Dychkov, S.N. Antipov, et al., JETP Lett, 5-6, 414 (2007).

Minkova Natalia
Multiparticle statistical approach to plasma modeling

Natalia R. Minkova
Tomsk State University, FTF, Lenin Ave., 36, Tomsk, 634050, Russia

The classical statistical approach is based on the assumption that coordinates of all particles are distinguishable what results in one-particle kinetic models. By considering finite instrumental resolution scales we have to suppose that particles' coordinates are indistinguishable within a probing volume. This approach produces models [1,2] that are based on multiparticle probability functions reduced from a probability function of total particles' system. The latter is separated as a subsystem of plasma (gas) flow that is in dynamic equilibrium with surroundings. The probability function of the subsystem satisfies Liuoville theorem (conservation of elementary phase volume) if hypothesis of detailed dynamic equilibrium is assumed. The produced multiparticle models describe plasma flows in terms of fluctuations of macroscopic parameters. The discussed approach contributes to solving the Gibbs' paradox. The discussed approach is tested by wellknown classical problems and demonstrated by its application to modeling of solar wind plasma flow. The derived macroscopic parameters (density and speed) coincide under some simplifying assumptions with results of the two-particle kinetic model [3] that are consistent with observational data for solar wind (one-particle kinetic models do not provide the observed solar plasma acceleration under the same assumption).

[1] N.R.Minkova Izvestija vuzof. Physics (Russian Physics Journal) 47, 10 (Special issue on Applied problems of mechanics of continua), 73-80 (2004).
[2] Minkova N.R. GSI-Report GSI-2007-2, 79 (2007).
[3] Y. M.Vasenin, N.R.Minkova, A.V.Shamin, AIP Conference Proceedings 669, series Plasma Physics: 11th International Congress on Plasma Physics: ICPP2002. 516-519 (2003).
[4] Y.M.Vasenin, N.R Minkova. Jour. Phys. A 36, 22, 6215-6220 (2003).

Morozov Igor

Approaches to the Simulation of Nonideal Plasmas by the Method of Wave Packet Molecular Dynamic

Igor V. Morozov, Ilya A. Valuev
Joint Institute for High Temperatures of RAS, Izhorskaya, 13-2, Moscow 125412, Russia

The method of Wave Packet Molecular Dynamics (WPMD) was applied originally in [1,2] to study the dynamical response of electron-ion nonideal plasmas with nonideality parameter in range $\Gamma = 0.5 - 2$. In contrast to the classical Molecular Dynamics, the electrons in WPMD are treated as Gaussian wavepackets (WP). It is expected that this method is more accurate to account for quantum effect of close particle collisions compared to the pseudopotential approach, traditionally used in plasma Molecular Dynamics. The most elaborate and computationally demanding version of the method is the antisymmetrized WPMD (AWPMD) [1,3], where the electron spins are explicitly treated by the single determinant antisymmetrization of the trial wave function. In contrast to the pseudopotentials having adjustable parameters, the WPMD is its original formulation is a fully ab-initio method.

At the same time the WPMD has some intrinsic limitations connected with the poor representation of an electron by a single Gaussian. This results, among other unwanted effects, in the unlimited broadening of the WP, making the model inconsistent. This problem can be partially solved by imposing additional forces to fix the average value of WP width (introducing an additional empirical parameter to the model) or by using antisymmetrized WPs [3], where the finite widths are determined by symmetry effects.

In the present work we develop an alternative nearest image AWPMD scheme, which is slightly different from [1,3] in the way of implementing periodic boundary conditions in the simulation box. The real space treatment of WPs brings more flexibility to the interaction calculation. For example, it permits to treat the particles classically in case of weak interaction. The results for both antisymmetrized and non-antisymmetrized WPMD are compared and possible solutions to the problem of WP broadening are suggested. Comparison between different models are made with respect to the calculation of the dynamical plasma conductivity or the effective collision rate.

[1] M. Knaup, P.G. Reinhard, C. Toepffer, G. Zwicknagel, J. Phys. A, 36, 6165 (2003).
[2] G. Zwicknagel, T. Pschiwul, J. Phys. A, 39, 4359 (2003).
[3] B. Jakob, P.-G. Reinhard, C. Toepffer, G. Zwicknagel, Phys. Rev. E, 76, 036406 (2007).

Murillo Michael
The Role of Dynamical Screening in Temperature Relaxation of Non-Equilibrium Dense Plasmas

Michael S. Murillo, Chandre Dharma-wardana
Los Alamos National Laboratory
National Research Council, Canada

Achieving ignition in the laboratory is a multi-billion dollar effort that promises nearly unlimited energy. Among the various physical processes that we must understand, such as the timing of shocks, overall energy balance is crucial. The energy balance issue can be understood by considering the various couplings between the different species. Fusion fuel burns to produce fast charge particles that either escape or transfer their energy predominately to the electrons. The electrons in turn couple most strongly to the radiation which largely escapes. As the fusion cross section is strongly temperature dependent, it is imperative to retain the ion temperature or, preferably, raise it to the peak of the burn rate. This can only be done through electron-ion collisions, since the radiation-ion coupling is extremely weak. Because of the importance of this problem, we have addressed the issue of electron-ion equilibrium in dense, hot hydrogen plasmas [1]. We have employed three different techniques, and have compared with the usual Landau-Spitzer (LS) model that is assumed to be accurate at high temperature. We have extended two versions of a quantum-many approach that has been used to describe this process under liquid-metal conditions [2]. The two approaches both include dynamical screening, but at different levels of sophistication. We have also employed non-equilibrium molecular dynamics simulations that provide a nearly exact description of the relaxation process. In the simulations, the only adjustable physics is the form of the effective quantum potentials between the particles. We carried out a very detailed study of such potentials under two-temperature conditions [3], and found that the results are very insensitive to the form used. For the temperature and density ranges that we considered (tens of eV to over a kilovolt at $r_s = 0.5$ and 1.0), we find that all of our approaches predict a relaxation time longer than the LS result, implying that energy flows back into the ionic fuel more slowly than previously believed. Although all approaches appear to approach the LS result at very high temperature, this result persists even under ignition conditions.

[1] M. S. Murillo and M. W. C. Dharma-wardana, submitted.
[2] M. W. C. Dharma-wardana and Perrot, Phys. Rev. E 58, 3705 (1998).
[3] M. W. C. Dharma-wardana and M. S. Murillo, Phys. Rev. E 77, 026401 (2008).

Omarbakiyeva Yultuz
The electron-atom interaction in partially ionized dense plasmas

Y.A. Omarbakiyeva (1), T.S. Ramazanov (1), G. Roepke (2)
(1)IETP, Al Farabi Kazakh National University, 96a, Tole bi St., Almaty,050012, Kazakhstan
(2)Institute of Physics, University of Rostock, D-18051, Rostock, Germany

At present electron - atom interaction is the most unclear phenomena in evaluating thermodynamic and transport properties of partially-ionized plasmas. It is known that the most long range force of charge-neutral interaction is polarization interaction. Polarization effective potential for electron-atom interaction in semi-classical plasma was suggested in Ref. [1]. Elastic scattering of electrons on atoms was investigated on the basis of the suggested pseudopotential model [2]. The short-range behaviour of the effective interaction between the atom and an electron needs more detailed consideration. One of the effects at small distances is the diffraction effect of particles, which has been taken into account in the polarization pseudopotential model [1]. The symmetry effect has to be also considered. In principle, we have to consider two possibilities for the spin orientations of the electrons. If the spins of the free as well as the bound electrons are parallel, due to the Pauli Exclusion Principle we have a strong repulsion at short distances. Of special interest is role non-local interaction which is necessary to describe exchange interaction. The separable potential is constructed by scattering data and effective radius theory. Parameters of the interaction potential were obtained on the basis of the scattering data, such as phase shifts, scattering length, the effective radius [3,4,5]. The influence of Pauli Exclusion Principle on phase shifts and binding energy is considered. Taking into account of the Pauli blocking leads to qualitative changing of scattering phase shifts behaviour at high densities.

[1] T.S. Ramazanov, K.N. Dzhumagulova, Y.A. Omarbakiyeva, Phys. Plasmas. 9, 092702 (2005).
[2] T.S. Ramazanov, K.N. Dzhumagulova, Yu.A. Omarbakiyeva, G. Röpke, Contr. Plasma Physics. 47, 267 (2007).
[3] C. Schwartz, Phys. Rev. 124, 1468 (1961).
[4] M.V. Faasen, A. Wasserman, E. Engel, F. Zhang, K. Burke, Phys. Rev. Lett. 99, 043005 (2007).
[5] T. Scholz, P. Scott, P.G. Burke, J. Phys. B. 21, L139 (1988).

Pavlov Georgy
Non-linear response theory in non-ideal charged matter

Pavlov G.A.
Institute of problems of chemical physics, Chernogoloka, Moscow region, 142432, Russia

The nonlinear response theory approaches are developed to study the nonlinear phenomena and nonlinear transport in non-ideal Coulomb systems. The nonlinear phenomena: plasma wave echo and waves transformation have been investigated under non-ideal Coulomb system conditions based on a variant of the nonlinear response theory. The model for the determination of quadratic response functions is presented, which uses frequency moments and explicit approximations of corresponding response functions. The conditions for experimental realization of the mentioned phenomena in non-ideal plasma are examined. It is shown that ultra-short field pulses can induce the phenomena. Other nonlinear phenomena in non-ideal charged matter can be considered in the offered way. In these cases the studying of frequency moments and explicit approximations of response functions, described given nonlinear phenomena, would be performed. The theory of non-linear transport is elaborated to determine the Burnett transport properties of non-ideal multi-element plasma. The procedure of the comparison of the phenomenological conservation equations of a continuous charged medium and the microscopic equations for dynamical variables is used for the definition of these properties. The Mori's algorithm is developed to derive the equations of motion of dynamical value operators of a non-ideal system in the form of the generalized nonlinear Langevin equations. In consequence, the response function expressions of kinetic coefficients corresponding to second order thermal disturbances (temperature, mass velocity, etc) have been found in the long-wavelength and low frequency limits. To establish a link between the results of the performed investigations and hydrodynamic problems the properties of the matrix of coefficients at highest derivatives in the set of conservation equations in the linearized Burnett approximation are discussed. The approach for non-linear transport properties definitions can be used for different dense matter: one and two-component Coulomb systems, electrolytes, liquid metals, nuclear matter etc and for dense neutral isotropic matter. It is important also to provide the calculation of Burnett kinetic coefficients of non-ideal matter, for instance, by computer modeling. The report shows the difference and similarity between the variants of non-linear response theory: the description of nonlinear phenomena and nonlinear transport in non-ideal charged matter.

Radhi Raad
Coulomb excitations of open sd-shell nuclei

R.A Radhi
Department of Physics, College of Science, University of Baghdad, Baghdad,Iraq

Coulomb excitations of open sd-shell nuclei are investigated. Microscopic theory is employed to calculate the C2 form factors for the first two 2+ states in 22Ne, 26Mg and 30Si. These collective transitions are discussed taking into account core-polarization effects. These effects are included through one-particle one-hole excitations from the 1s and 1p core orbits and also from the 2s1d active model space orbits to all higher allowed orbits with excitations up to 10 $\hbar\omega$, where a sufficient convergence is obtained in the Coulomb matrix elements. Remarkable agreements are obtained between the measured and calculated form factors for the first 2+ states. The second 2+ states are less affected.

Raitza Thomas
Dynamical Collision Frequency in Laser Excited Clusters

Thomas Raitza, Heidi Reinholz and Gerd Röpke
Universität Rostock, Universitätsplatz 3, 18055 Rostock

One of the fundamental quantities in the physics of strongly coupled Coulomb systems is the dynamical collision frequency. Collisions are of relevance for emission, absorption, reflection and scattering of light. Analytical as well as MD simulation techniques [1 - 3] have been applied to evaluate the dynamical collision frequency for homogeneous systems, with special application to optical properties. Recently, clusters at nearly solid densities are more accessible to experimental investigations [4] using laser intensities of $10^{13} - 10^{16}\,\mathrm{Wcm}^{-2}$. Here, we present theoretical results for finite Coulomb systems. In particular, we are interested in the cluster size dependence of the collisional damping rates in comparison to bulk systems. Laser excited Na_{55}, Na_{147} and Na_{309} clusters are investigated using a MD code [5]. For more details on the different stages of the cluster expansion at a given time instant, relaxation into quasi-equilibrium was adjusted. For this, the ion geometry was frozen at different time intervals after laser injection. Restricted MD simulations at those given ion positions allow to consider electron dynamics only. Single time properties of the nanoplasma in quasi-equilibrium are considered. The charge Z of the cluster, a homogeneous temperature as well as a radial electron density profile were deduced. Using restricted MD simulations, electron current auto-correlation functions are extracted. From its Laplace transformations, the spectral features are analyzed [6]. Several resonance frequencies of the electron cloud are identified. The position of the resonance frequencies as well as the damping behaviour were investigated for different electron temperatures and densities using Lorentzian fits. Compared with bulk plasmas, the collision frequency in nanoplasmas is reduced.

[1] H. Reinholz, R. Redmer, G. Röpke, and A. Wierling; Phys. Rev. E 62, 5648 (2000).
[2] I. Morozov, H. Reinholz, G. Röpke, A. Wierling, and G. Zwicknagel; Phys. Rev. E 71, 066408 (2005).
[3] H. Reinholz; Ann. Phys. Fr. 30, N° 4 - 5 (2006).
[4]T. Döppner, Th. Diederich, A. Przystawik, N. X. Truong, Th. Fennel, J. Tiggesbäumker, and K. -H. Meiwes-Broer; Phys. Chem. 9, 4639 (2007).
[5] M. Belkacem, F. Megi, P.-G. Reinhard, E. Suraud, and G. Zwicknagel; Eur. Phys. J. D 40, 247 (2006).
[6] R. Reinholz, T. Raitza, and G. Röpke; Int. J. Mod. Phys. B 21, 2460 (2007).

Ramazanov Tlekkabul

Kinetic and thermodynamic properties of a dense metal plasmas

T.S.Ramazanov (1), K.N.Dzhumagulova (1), M.T.Gabdullin (1), A.Zh.Akbar (1), R.Redmer (2)
(1) IETP, Al Farabi Kazakh National University, 96a, Tole bi str., Almaty 050012, Kazakhstan
(2) Institute of Physics, University of Rostock, D-18051, Rostock, Germany

In this work the ionization equilibrium, thermodynamic and kinetic properties of a dense semiclassical nonideal metal plasmas were investigated. To describe the electron-ion interaction the pseudopotential, which takes into account the effects: charge screening at long distances and quantum effect of diffraction occurs in a dense systems, was used [1]. The electron-atomic interaction was described by polarization pseudopotential [2], which also takes into account the screening effects and quantum effects of diffraction. In first part of this work we studied the thermodynamic properties of Cu and Al plasmas (equation of state and internal energy). The nonideal plasma consisting of electrons, ions of different multiplisity and atoms was considered. In terms of the pseudopotential model the excess of chemical potential of charge particles was calculated. At the investigation of ionization stages we used the Saha equations with corrections to nonideality (lowering of ionization potentials) [3]. In the second part of work the phase shifts and cross sections of particles scattering in a dense semiclassical aluminum plasma were calculated. For determination of the phase shifts the Calogero equation [4] was numerically solved. Total scattering cross section of electron-atomic interaction was compared with the data of work [5], in which the scattering processes have been studied on the basis of the physical model of plasma. Also in this part the phenomenon of electrons runaway for a dense plasma was considered too. The collision frequency and other characteristics of this phenomenon were obtained. For strongly correlated classical system electrons runway was considered in work [6]. It is shown that the probability of electron's runaway in dense plasma is greater than for rarefied plasma.

[1] T.S. Ramazanov, K.N. Dzhumagulova, Phys. Plasmas, 9, 3758 (2002).
[2] T.S. Ramazanov, K.N.Dzhumagulova, Yu.A. Omarbakiyeva, Phys.Plasmas, 12, 092702 (2005).
[3] R. Redmer, Phys. Rev. E 59, 1073-1081 (1999).
[4] V.V. Babikov, The Method of Phase Functions in Quantum Mechanics: Moskva:Nauka, 1988.[in Russian]
[5] J.-C. Pain, T. Blenski, Journal of Quantitative Spectroscopy and Radiative Transfer, 81 (2005) 355-369.
[6] T.S. Ramazanov, K.M. Turekhanova, Contrib. Plasma. Phys., 43, 338 (2003).

Reinholz Heidi
Diagnostics of dense Coulomb systems via transport and optical properties

H. Reinholz
Universität Rostock, Institut für Physik

Transport and optical properties of Coulomb systems are described by the dielectric function, which is related to correlation functions such as density, current, or force auto-correlation functions [1]. Deduction of plasma parameters from such quantities as reflectivity, absorption, thermoelectric properties or spectral line shapes is investigated. Central quantity of interest is the free electron density since it can't be measured directly but is crucial for the plasma properties. For the evaluation of equilibrium auto-correlation functions at arbitrary coupling strength we can apply MD simulation techniques for classical systems. Using pseudopotentials in order to mimic quantum effects, correlation functions are evaluated for bulk systems and finite clusters [2,3]. We find a more structured frequency spectrum of plasma correlations in clusters indicating several collective modes. Size effects have been found for the damping of plasma oscillations [3,4]. Alternatively, analytical calculations for quantum systems can be performed in the weak coupling region. The dynamical collision frequency for bulk systems is evaluated in different approximations systematically and consistently by including strong collisions, dynamical screening, electron-electron interactions and effects due to partial ionization in the plasma state [1]. Good agreement is found with MD simulations [2]. Using the concept of dynamical collision frequency, the influence of collisions on such properties as absorption and reflection, Thomson scattering, static and dynamic conductivity has been considered. In particular we will reconsider the dc-conductivity in inert gases [5] and, in this context, discuss the so-called Coulomb contribution [6]. We also investigated the influence of the plasma environment on spectral line shapes [7]. Improving the RPA dielectric function, collisions prove to be of relevance in strongly coupled plasmas. In the context of the analysis of experiments, those can be seen as diagnostic tools for the free electron density in plasma systems.

[1] H. Reinholz, Ann. Phys. Fr 30 No 4-5 (2005).
[2] I. Morozov, et al. Phys. Rev. E 71 (2005) 066408.
[3] H. Reinholz, T. Raitza et al., Int. J. Mod. Phys. B 21 (2007) 2460.
[4] L. Ramunno et al., J. Phys. B: At. Mol. Opt. Phys. 39 (2006) 1.
[5] J. R. Adams et al., Phys. Rev. E 76 (2007) 036405.
[6] J. R. Adams et al., Phys. of Plasmas 14 (2007) 062303.
[7] A. Sengebusch et al., Contrib. Plasma Phys. 47 (2007) 309.

Tkachenko Igor M.
Energy losses of fast projectiles in dense multi-component plasmas

D. Ballester(1) and I. M. Tkachenko(2)
(1) School of Mathematics and Physics, Queen's University, Belfast BT7 1NN, United Kingdom (2) Institute of Pure and Applied Mathematics, Polythecnic University of Valencia, 46022 Valencia, Spain

The modification is studied of the Bethe-Larkin expression for the electron gas stopping power due to the presence of ion components, strong coupling and the Langmuir mode decay. For a perfectly defined plasma collective mode with negligible damping, the fast-projectile asymptotic form of the stopping power is affected by the electron-ion correlation. Precisely, in a dense hydrogen plasma, the electronic plasma frequency is substituted by the long-wavelength asymptotic form of the Langmuir mode related to the probability to find both electron and proton at the same point. This factor is evaluated in the random phase approximation as a leading term of the Matsubara frequency expansion and the significance of the correction is estimated numerically. In addition, the bounds for the fast projectile asymptotic form are determined on the basis of well-established results of the linear response theory of Coulomb systems, namely, the zero-frequency sum rule, the f-sum rule, the fourth moment sum rule, and the fluctuation dissipation theorem, together with the compressibility sum rule. This general result constitutes a sum rule for the calculation or numerical estimate of the fast projectile stopping power for any model dielectric function satisfying the above-mentioned conditions, not only in plasma physics, but also in systems of condensed matter physics, such as the electron gas, as well as other multi-component uniform charged particle models. Generalization to more complex Coulomb systems is straightforward. The results are to contribute to the correct interpretation of the experimental data, which could permit to test the existing and future models of thermodynamic, static and dynamic characteristics of strongly coupled Coulomb systems.

Tkachenko Igor M.
Static correlation functions in hydrogen-like completely ionized plasmas

M.J. Corbatón and I. M. Tkachenko
Department of Applied Mathematics, HTSIE, Polytechnic University, 46022 Valencia, Spain; imtk@mat.upv.es

The probability to find an electron and an ion at the same point in a dense hydrogen-like plasma is estimated using the temperature Green function method within the improved random-phase approximation. The results are important for the calculation of the plasma dynamic characteristics like the stopping power and the charge-charge dynamic structure factor.

Tkachenko Igor M.
Transport properties of shock-compressed Xe revisited

J. Alcober and I.M. Tkachenko
Department of Applied Mathematics, Polytechnic University of Valencia, 46022 Valencia, Spain; imtk@mat.upv.es

The self-consistent method of calculation of kinetic coefficients of strongly coupled plasmas [1] is applied to shock-compressed multi-species Xe plasmas under the conditions of almost complete ionization. A semi-quantitative agreement with experimental data [2] is obtained. A broader comparison with the experimental and verification of the composition data is planned.

[1] I.M. Tkachenko, P. Fernández de Córdoba, Phys. Rev. E, 57, 2222 (1998); V.M. Adamyan, I.M. Tkachenko, Condensed Matter Physics, 3, 641 (2000) and references therein.
[2] S. Kuhlbrodt et al., Contr. Plasma Phys., 45, 61 (2005).

Turekhanova Kunduz
On phenomenon of electron's runaway in partially ionized nonideal plasma

T.S. Ramazanov, K.M. Turekhanova
IETP, al-Farabi Kazakh National University, 96A Tole bi, 050012 Almaty, Kazakhstan

The investigation of electron's runaway phenomenon is of fundamental and practical interests, because the superthermal electrons determine velocities of ionization and excitation of plasma neutral components [1,2]. In a tokamak plasma runaway electrons are generated above a critical energy due to decreasing in the Coulomb collision frequency with the electron energy. In this connection it is necessary to analyze the probability of electron's runaway in a system at the investigation of nonideal plasmas' physical properties and their numerical simulations [3,4]. In the present work we consider partially ionized hydrogen plasma. For description of interaction between charged particles we have used the pseudopotential taking into account collective effects [5] and the well-known effective screened polarized Buchingham potential as the model potential of charged–atom interaction in partially ionized nonideal plasma [6,7]. At the investigation of composition of plasma we used the Saha equation with corrections to nonideality (lowering of ionization potentials). The Saha equation was solved for obtaining of plasma ionization stages at the different number density and temperature. Knowing of plasma's composition we can investigate the effect of electron's runway in partially ionized hydrogen plasma. The results of calculating of the electron's collision frequency are presented in this work. It is shown that the values of the frequency of electron's collision for partially ionized hydrogen plasma are situated lower than the case of fully ionized hydrogen plasma in the definite range of nonideality parameter. Also in this work there are defined the conditions of electrons runaway on the basis of the pseudopotential models. The results are compared with data of asymptotic theories.

[1] A.S. Sharma. Nucl. Fusion. 3, 491 (1988).
[2] J.R. Martin-Solis. et.all. Nucl. Fusion 44, 974 (2004).
[3] T.S. Ramazanov, K.M. Turekhanova. Contrib. Plasma. Phys. 43, 338 (2003).
[4] T.S. Ramazanov, K.M. Turekhanova. Phys. Plasmas 12, 102502 (2005).
[5] F.B. Baimbetov, Kh.T. Nurekenov, T.S. Ramazanov. Phys. Letters A. 202, 211 (1995).
[6] D. Kremp, G. Ropke, M.Schlanges Transport properties in dense plasmas. Berlin, (1984).
[7] R. Redmer. Phys. Rep. 35, 1282 (1997).

Vorberger Jan
Theory and ab initio Simulations forX-Ray Scattering in Warm Dense Matter

J. Vorberger, K. Wuensch, and D.O. Gericke
CFSA, Department of Physics, University of Warwick, Coventry CV4 7AL, UK

X-ray scattering is an emerging new diagnostic method for dense plasmas and warm dense matter. For dense plasmas, it is particularly interesting since most other methods fail for systems that are opaque in the visible. The scattering spectrum usually shows two distinct features: a large peak around the incident wave length (ion feature) and one or two frequency-shifted peaks associated with the collective scattering from free electrons (plasmon peaks). Theoretical predictions for both features are needed to obtain all plasma properties from the measured scattering spectrum.
The contribution from the free electrons is rather easily described by the random phase approximation (RPA) since the electrons are in most cases only weakly coupled due to their small charge and, for very dense plasmas, due to degeneracy. Information about the electrons associated with the strongly correlated ions is much harder to obtain. We use first principle quantum simulations (DFT-MD) and classical integral equations (HNC) to calculate both the ionic structure and the electron cloud around the ions. The latter technique has been generalised to treat multi-component plasmas. We apply our method to warm dense aluminium, plastics, lithium and beryllium and compare to recent experiments.
Our analysis shows that HNC solutions for electron-ion systems have very limited predictive power since the results strongly depend on the form of the applied quantum pseudo-potential. However, simple one component calculations using the well-known linear screening model for the strongly coupled ions predict the ionic structure rather well when compared to both ab initio simulations and experiments. The combination of the techniques also allows for deeper insights into the properties of warm dense matter: we found strongly repulsive short range part of the ion-ion potential and bound state wave functions broadened by correlations. Finally, we constructed the weight of the ion peak in the scattering spectrum from the information obtained and found very good agreement with the measured data for well-tested warm dense Beryllium.

Wierling August
Dynamic local field corrections for two-component plasmas at intermediate coupling

August Wierling
Universitaet Rostock, Institute of Physics, 18051 Rostock, Germany

The dielectric tensor is a key quantity in the analysis of dense plasmas. It is closely related to the (non-local) reflectivity,the absorption coefficient for electro-magnetic radiation, the generalized non-local collision frequency, and the dynamic structure factor. In non-ideal plasmas, the dielectric tensor has to be treated beyond the random phase approximations. Correlations as well as collisions have to be included.These corrections are known as (dynamic) local field corrections.
Based on the Zubarev approach to linear response theory [1], two avenues for an approximative description of dynamic local field corrections in two-component plasmas at intermediate coupling and arbitrary degeneracy are presented. In the first approach, we generalize the perturbative one-moment treatment of Reinholz et al. [2] to finite values of the wave-vector. A systematic account of collisions as well as dynamical screening is implemented by a diagrammatic analysis with the help of thermodynamic Green functions. The importance of higher order moments is carefully checked.
In a second approach, a relaxation time approximation is proposed as an interpolation scheme between static local field corrections in the interacting electron gas and the Drude model for the dynamic conductivity. This approach generalizes the Mermin scheme [3,4] by taking into account electron-electron correlations. Exploratory calculations are performed for impurity scattering in an electron gas at T=0 as well as a hydrogen plasma in the non-degenerate limit.For the electron gas, static local field corrections due to Farid et al.[5] are used in describing the interacting electron gas.
In both approximations, special attention is given to sum rules for the response function. Also, the influence of collisions and correlations on the plasmon dispersion is investigated. With the help of the dynamic local field corrections, the dynamic structure factor of a hydrogen plasma at intermediate coupling and for non-degenerate conditions is determined. Implications for plasma diagnostics are discussed.

[1] G. Roepke and A. Wierling, Phys. Rev. E 57, 7075 (1998).
[2] H. Reinholz et al., Phys. Rev. E 62, 5648 (2000).
[3] N.D. Mermin, Phys. Rev. B 1, 2362 (1973).
[4] G. Roepke et al., Phys. Lett. A 260, 365 (1999).
[5] B. Farid et al., Phys. Rev. B 48, 11602 (1993).

Wuensch Kathrin
Ion Structure in Warm Dense Matter: ab initio Simulations versus HNC

K. Wuensch, J. Vorberger and D.O. Gericke
Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, UK

Structural information for warm dense matter (WDM) are of interest for the understanding of astrophysical plasmas as in giant gas planets and for inertial confinement fusion where it occurs as a transient state. In particular, the well-pronounced ionic structure strongly influences the equation of state as well as transport coefficients. As WDM is characterised by near solid densities and temperatures around a few electronvolts, the ions are strongly coupled and the electrons are partially degenerate. The combination of both makes usual expansion techniques as well as many other standard procedures inapplicable.
In this contribution, we compare two very different approaches for the ionic structure in WDM. First we employ classical integral equations that are well-suited for the description of classical, strongly coupled systems. We apply two flavours: one treats only ions with effective interactions, the other coupled electron-ion systems. The latter requires a multi-component version of the usual HNC scheme that is also used to investigate systems with multiple ion species. For electron-ion systems, we have to apply pseudo-potentials that are designed to mimic the quantum nature of the electrons. However, different kinds of potentials suggested yield very different results for both the electron as well as the ion structure. We therefore compare these results with ab-initio quantum simulations, i.e., density functional molecular dynamics (DFT-MD), which can treat strongly coupled ions as well as degenerate electrons. Since these simulations are computationally very demanding, it would be very advantages to obtain similar information from a fast technique such as HNC.
The comparison shows that all quantum pseudo-potentials tested yield very poor results compared to DFT-MD. In contrast, the much simpler Yukawa-model that uses linearly screened ions, seems to work rather well when degeneracy is accounted for in the screening length. The results can be further improved by considering a strongly repulsive potential that mimics the interaction of two full 1s shells for warm dense beryllium. Finally, we investigate plasmas with multiple ion species, such as CH and LiH, and show that an one-component treatment with an average charge state becomes inapplicable for strongly coupled ions.

Zmievskaya Galina
Non-linear Brownian Motion Model and its Computer Simulation

Galina Zmievskaya, Anna Bondareva and Tatiana Levchenko
M.V. Keldysh Institute of applied mathematics of Russian Academy of Sciences, Miusskaya sq.4, 125047 Moscow, Russia

Computer analysis and fundamental aspects of the both:clustering non steady state processes at fluctuation stage of first order phase transition and clusters brownian motion which can be initiated by long-range self-consistent potentials of its indirect(through the acoustic lattice phonons) interaction are discussed. Quasilinear kinetic equations (Fokker-Planck-Kolmogorov, Einstein-Smolukhovskii) solution using stable and effective computer simulation methods is based on the strict results of probability analysis of mathematical physics equations and computer simulation tecnique. The solution of Ito-Stratonovich stochastic differential equations which are related with kinetic equations above mentioned gives us new information conserning the self-organization of "open plasma-like" media accounting the follows:sizes dependent Gibbs free energy of cluster formation and alternating-sign long-range potentials of cluster indirect interaction. Stochastic analog simulation method and its algorithms can be required in many applications.

[1] G.I.Zmievskaya, A.L.Bondareva, T.V.Levchenko, V.D.Levchenko, J.Phys.**D**:Appl.Phys.**40**(2007), 4842-9.
[2] S.s.Artem'ev and T.A.Averina, Numerical Analysis of Systems of ordinary and Stochastic Differential Equations (Utrecht, The Netherlands).

Ultracold plasmas

Killian Thomas
Watching Ions Dance Near Absolute Zero

Thomas C. Killian
Department of Physics & Astronomy, Rice University; Houston, TX 77005, U.S.A.

Ultracold neutral plasmas, formed by photoionizing laser-cooled atoms near the ionization threshold, stretch the boundaries of traditional neutral plasma physics. The electron temperature in these plasmas is from 1-1000K and the ion temperature is around 1 K. The density can be as high as 1010 cm-3. They provide a playground for studying strongly coupled plasmas, in which the Coulomb interaction energy exceeds the thermal energy. Strong coupling is of interest in many areas of physics, and in ultracold plasmas it leads to spatial correlations and surprising equilibration dynamics. The expansion of ultracold plasmas into the surrounding vacuum can also probe the physics of plasmas produced with short-pulse laser irradiation of solid, liquid, foil, and cluster targets. Our understanding of ultracold plasmas has increased dramatically due to theoretical and experimental work over the last several years. I will review our understanding of the expansion of the plasma and equilibration of the electrons and ions, and also point out recently examined topics such as the effect of magnetic fields and thermal transport in the strongly-coupled ion fluid. I will briefly mention new work with ultracold strontium plasmas, such as the use of expansion of the ions to measure the electron temperature, which evolves in complex fashion due to three-body recombination, disorder-induced heating, and adiabatic cooling. Also, a new spectroscopic probe geometry that separates ion expansion from ion thermal motion has allowed study of the ion temperature during the entire evolution of the plasma. Preliminary results indicate an anomalously large heating rate for the ions that prevents the ion Coulomb coupling parameter from increasing during the adiabatic expansion. This work is supported by the U.S. National Science Foundation and David and Lucille Packard Foundation.

Rolston Steven
Electrons in Ultracold Plasmas

Steven L. Rolston
Joint Quantum Institute, Department of Physics University of Maryland, College Park, MD, USA

Ultracold plasmas, formed by the photo-ionization of a sample of laser-cooled atoms, have extended the parameter range of neutral plasma physics by two orders of magnitude to electron and ion temperatures below one Kelvin. In experiments performed to date, the plasmas are unconfined, and expand into vacuum. This leads to a dynamically evolving electron temperature as the expansion is driven by electron pressure, leading to adiabatic cooling, which is in turn counteracted by heating due to recombination collisions. By detecting the highly excited Rydberg atoms created in these collisions, we can monitor the temperature and find that the electrons are not quite strongly coupled. We have probed the ultracold plasma by exciting collective modes with RF electric fields, observing Tonks-Dattner resonances (electron standing sound waves). We have recently observed spontaneous periodic emission of bursts of electrons from an ultracold plasma in weak crossed electric and magnetic fields, a signature of a plasma instability, which we have tentatively identified as a high frequency drift instability.

Murillo Michael
Ultrafast Dynamics of Neutral, Ultracold Plasmas

Michael S. Murillo
Los Alamos National Laboratory

It is now possible [1] to form neutral plasmas in the micro-Kelvin regime by photo-ionizing a dilute atomic gas. Such plasmas - termed neutral ultracold plasmas (UCPs) - have enormous Coulomb coupling parameters in the hundreds of thousands. Based upon the various discoveries that have been about UCPs, it is quite clear that they share few properties with their non-neutral counterparts. In particular, it has been shown theoretically [2], and measured experimentally [3], that UCPs are intrinsically non-equilibrium strongly coupled systems. Interestingly, the experimental data has revealed that the average kinetic energy (effective temperature) oscillates as it approaches equilibrium. This has been interpreted as an effect of dynamical screening (or collective modes) similar to those that cause oscillations of the velocity autocorrelation function. Recently, it has been shown [4] that these interpretations are not quite correct. By performing a short-time expansion of the effective temperature, it can be shown that the short-time dynamics takes place based on correlation information before the photo-ionization has occurred; that is, the growth rate of the effective temperature depends on the plasma microfield for a completely uncorrelated system. Not surprising, at intermediate times, the evolution depends on many-body correlations that are cumbersome to compute. Therefore, nonequilibrium molecular dynamics has been used to explore the entire evolution of an UCP, assuming a homogeneous UCP (approximately, the central region). The predictions of the short-time expansion are verified, and further details of the evolution can be extracted. Most important among the features revealed by the simulations is that the temperature oscillations are due to the formation of the pair correlation function; this is shown by comparing time-dependent correlation functions and velocity fields.

[1] T. C. Killian, "Ultracold Neutral Plasmas," Science 316, 705 (2007).
[2] M. S. Murillo, "Using Fermi Statistics to Create Strongly Coupled Ion Plasmas in Atom Traps," Phys. Rev. Lett. 87, 115003 (2001).
[3] Y. C. Chen et al., "Electron Screening and Kinetic-Energy Oscillations in a Strongly Coupled Plasma," Phys. Rev. Lett. 93, 265003 (2004).
[4] M. S. Murillo, "Ultrafast Dynamics of Strongly Coupled Plasmas," Phys. Rev. Lett. 96, 165001 (2006).

Ultracold plasmas - Posters

Zelener Boris

Electron-induced collisional transfer rates between Rydberg levels for the ultracold plasma

Bronin S.Ya., Khikhulkha D.R., Zelener B.B., Zelener B.V.
Joint of High Temperature Institute of RAS, Ijzorskaja 13, Moscow, Russia

The temperature dependence of the electron-induced collisional transfer rates between Rydberg levels for the ultracold plasma is discussed. The comparison of the difference theories with the experiment is made in the range of the temperatures T=300 – 7000 K. It is shown that the transfer rates are uncorrectly used for the electron-induced energy Ee < 100 K. The experimental and theoretical data of the transfer rates between Rydberg levels are absent in the rangeT=0-300K. That's why using of the relationship between the de-excitation transfer rate and the derivative of the excitation cross section in the thresholds is suggested. The Rydberg atom excitation cross sections from [1] are used. The transfer rates determined by these cross sections have a good agreement with experiment in the range of the temperatures T=300 – 7000 K. Then the Rydberg atom de-excitation transfer rate are obtained by using the detailed balance relation in the threshold. They depend from the initial and final energy of the threshold only. The calculations the time dependence of the Rydberg level concentrations were made with these de-excitation and excitation transfer rates. The number of the equations was determined from the relation $N = \sqrt{Ry/T}$, where Ry=13,6 ev. The number of the particles and the energy of the plasma are invariant. The calculation time is t < 10 mks, because was not account the expansion of the ultracold plasma.

[1] I. Percival, D.Richard, Adv.Atom.Mol.Phys. 11, 1, 1975

Biology and electrolytes

Alejandre Jose
Hydration and precipitation of ions in water

Jose Alejandre
Departamento de Quimica, Universidad Autonoma Metropolitana-Iztapalapa, Av. San Rafael Atlixco 186,Col. Vicentina, 09340 Mexico D.F., Mexico

The solubility of ions in water is important in disciplines as geology, colloidal systems, biological membranes and others. In a recent work Alejandre and Hansen [PRE,76, 061505 (2007)] found that nucleation is very sensitive to small changes in the potential field and that the repulsion interaction between hydrogen in water and chlorine ion plays a key role to induce precipitation of NaCl. In this work the correct behavior of ions in water at different concentrations and temperatures is obtained by simulation methods. The crystallization of ions was found for the first time at high ionic concentrations. Simulation results of ions at room temperature, supercritical conditions and at the liquid-vapor interface will be discussed. It will be shown that ions are hydrated at low concentrations and that precipitate at saturated conditions.

Muthukumar Murugappan
Soups of Coulomb Strings: Polyelectrolyte Physics

M. Muthukumar
Polymer Science and Engineering University of Massachusetts Amherst, MA 01003 USA

When many electrically charged monomers are strung together into polyelectrolyte molecules, such as DNA, proteins, and synthetic polyions, and dissolved in polar media, many puzzling phenomena arise. To mention a few, the disparity between the actual charge and the chemical charge on an isolated macromolecule, attraction between similarly charged macromolecules, independence of their electrophoretic mobilities on size and mass, and dramatic size changes of polyelectrolytic gels have intrigued the polymer physics and biological physics communities for decades. In the present lecture, only a modest amount of phenomenology and the basic conceptual framework will be addressed. Specific issues to be addressed are the following: 1. Effective charge of a macromolecule: When a topologically correlated polyelectrolyte chain is dispersed in aqueous media, counterions swarm within the Coulomb field created by the fluctuating polymer. The self-consistent coupling between the polymer conformations and the counterions determine the behavior of isolated polyelectrolyte chains. 2. Collective behavior of polyelectrolyte solutions: Interpenetration of charged strings in a neutralizing plasma leads to effective attraction between similarly charged strings and shrinkage of average sizes of isolated chains. Verification of new concepts by experiments will briefly be mentioned. 3. Phase behavior of polyelectrolyte solutions: The critical point associated with simple electrolyte solutions is significantly modified by the topological correlation of one kind of ions. Our theory of phase transitions of polyelectrolytes will be briefly mentioned, and compared with those of simple electrolytes. 4. Complexation between oppositely charged polyelectrolytes: By taking the example of the assembly of genomes in RNA viruses, the fundamental principle of genome structure will be presented based on electrostatics considerations.

Messina René

Crystalline structures in confined colloidal suspensions or dusty plasma

René Messina, Lahcen Assoud, Erdal Oguz, Hartmut Löwen
Institut fuer Theoretische Physik II Heinrich-Heine-Universitaet Duesseldorf Universitaetsstrasse 1 D-40225 Duesseldorf Germany

Understanding the structural phase diagram of confined highly charged particles (as realized in colloidal suspensions and/or dusty plasma) is of practical as well as fundamental interest. In this conference, I will consider two situations: (i) two-dimensional binary mixtures and (ii) multilayers.
The zero-temperature phase diagram of binary mixtures of (repulsive) particles interacting via a (screened Coulomb) Yukawa pair potential is presented [1]. The potential energy obtained by a lattice sum is minimized among a variety of candidate two-dimensional crystals. The resulting rich phase behavior as a function of composition and charge ratio is discussed.
Using lattice sums for screened and unscreened Coulomb potentials, we also explore the ground state phase diagram of multilayers. For the unscreened situation, we consider a neutralizing background that is homogeneously smeared out over the confining slit. Analytical results are obtained for the monolayer to bilayer transition and numerical ones for the phase behavior of multilayers. In the screened case a special attention is paid to the stability of multilayers as a function of the screening.

[1] L. Assoud, R. Messina and Hartmut Löwen, cond-mat arXiv:0801.1453

Biology and electrolytes - Posters

Blum Lesser

A New Analytical Theory For Real Electrolytes: The Extended Soft Binding Mean Spherical Approximation (ESBIMSA).

L. Blum(1,2), M. Arias(2), D. V. Perez (2)
(1)Chemical Engineering, Princeton University, Princeton NJ 08540 (2)Physics Department, University of Puerto Rico, Rio Piedras, PR 00931

The availability of powerful computers makes the simulation of biological systems an extremely useful tool: However due to the complexity of bio-systems one can never simulate the complete system with ions, water, and the proteins of the cell. There are a number of examples such as DNA replication, protein folding, ion channels, and in general the solvation problem in chemical kinetics, where we know that the electrostatic forces play the leading role. Either continuum dielectrics or some form of coarse graining (Brownian dynamics) needs to be used. We propose a simple yet amazingly accurate scheme for doing this, which is based on the fact that ionic mixtures obey screening laws (Perfect screening theorem) and simple asymptotic relations (Debye-Hueckel limiting law, Onsager-Rosenfeld limiting laws, Bjerrum-Wertheim association limits). This theory is based on the ESBIMSA (Extended Soft Binding Mean Spherical Approximation, L. Blum and M. Arias, Mol. Phys. (104), 3801, (2006)) that interpolates smoothly between the high density, and the low-density limit, (the EXP-BIMSA) which is the only theory that satisfies the full association limits.

The theory has been applied to a number of simple and also complex ionic systems with amazing success: For simple models of ion channels (A. Enriquez and L. Blum, Mol. Phys. (103), 3201, (2005)) the agreement is very good. For linear flexible Polyelectrolytes it yields perfect agreement with computer simulations (Phys. Revs. Letters 90, 043803, (2003)). For simple ionic mixtures, a similar interpolation scheme (Phys. Revs. E72 041501, (2005)) yields the best agreement with computer simulations.

Our new explicit analytical theory is now valid for the general different diameter ionic mixture, and satisfies an exact contact theorem (L.Blum and D.V. Perez, Cond. Mat. Phys (10), 381 (2007) as well as the virial-compressibility consistency of the equation of state.

The new theory is applicable to other interesting geometries such as helices.

High energy density plasmas

Fortov Vladimir
Investigation of the physical properties of strongly coupled plasmas by the dynamical methods

V.E.Fortov
Institute for High Energy Density Physics, RAS, Moscow

The physical properties of strongly coupled plasma at high energy densities are analyzed in a broad region of the phase diagram. The theoretical and experimental dynamical methods of hot dense plasma investigations are discussed. Main attention is paid to shock wave methods. Intense shock, rarefaction and radiative waves generated by high explosives lasers, heavy ion beams, soft X-rays and electrical explosions metals, bulk electron and ion heating were used for generation of extremely high temperatures and high pressures. The highly time-resolved diagnostics allow us to measure the thermodynamical, radiative, and electrophysical properties of high temperature condensed plasmas in the broad region of the phase diagram from compressed condensed solid states up to the low density gas range, including high temperature evaporation curves with near-critical states of metals, strongly coupled plasma, and metal-insulator transition regions. The pressure ionization phenomena in hydrogen, helium, argon, xenon, iodine, silica, sulfur, fullerenes, and some metals are analyzed on the base of multiple shock compression and electrical explosions experiments. The effect of "dielectrization" for some metals (Li, Na) is discussed on the base of the multiple shock compression experiment. The experimental results of metallization of AlH3 at megabars are analyzed in the framework of chemical compression models. Thermodynamical parameters of metal critical points are analyzed and compared with the theoretical predictions. The shock-wave-induced non-equilibrium phenomena at fast melting and adiabatical condensation are analyzed in the framework of the interspinodal decomposition model. The theoretical interpretation of the opacity measurements demonstrates strong deformation of discrete spectrum in coupled materials. The computer simulations of parameters of strongly coupled matter generated by the intense shock wave high sources are presented.

Toepffer Christian
Wave Packet Simulations for the Insulator-MetalTransition in Dense Hydrogen

B. Jakob, P.-G. Reinhard, C. Toepffer, G. Zwicknagel
Institut fuer Theoretische Physik II, Universitaet Erlangen, Germany

Dense hydrogen is studied in the framework of wave packet molecular dynamics. In this semiquantal many-body simulation method the electrons are represented by wave packets which are suitably parametrized. The equilibrium properties and the time evolution of the system are obtained with the help of a variational principle. At room temperature the results for the isotherms are in good agreement with anvil experiments [Loubeyre *et al.*, Nature 383, 702 (1996)]. At higher densities beyond the range of the experimental data a transition from a molecular to a metallic state is predicted. The wave packets become delocalized and the electrical conductivity increases sharply. The phase diagram is calculated in a wide range of the pressure-density-temperature space. The observed transition from the molecular to the metallic state is accompanied by an increase in density in agreement with recent reverberating shock wave experiments [Fortov et al., PRL 99, 185001 (2007)].

Dyer Gilliss

Equation of State Measurements of Warm Dense Matter Heated by Laser Accelerated MeV Protons

Gilliss Dyer (1), Byoung-ick Cho (1), Aaron Bernstein (1), Alan Dalton (1), Ronnie Shepherd (2), Hui Chen (2), Yuan Ping (2), Klaus Widmann (2), Jim Bonelie (2), Lee Elberson (2), Patrick Rambo (3), Jens Schwartz (3), Matthias Geissel (3), Erick Brambrink (3), Briggs Atherton (3), Aaron Edens (3), and Todd Ditmire (1)

(1) Texas Center for High Intensity Laser Science, The University of Texas at Austin; (2) Jupiter Laser Facility, Lawrence Livermore National Laboratory; (3) Z-Beamlet facility, Sandia National Laboratory

We present experimental results testing equation of state models of aluminum in the difficult thermodynamic regime of warm dense matter (WDM). By way of energetic protons generated by an ultrafast, ultra-intense laser pulse, we have flash-heated a several-micron thick aluminum foil sample to temperatures around 20 eV on a timescale of several picoseconds, faster than the dissociation time of the foil. We probed the heated foil using two simultaneous, independent, time-resolved measurements of quantities which are dependent on the equation of state: the thermal emission, measured using a streaked optical pyrometer (SOP), and the free expansion into vacuum, measured using a chirped-pulse intereferometer (CPI). Our experiment was performed on the Titan laser at Lawrence Livermore National Laboratory. Laser pulses delivered 100 J on target in a 600-700 ps pulse at 1054 nm. Our targets consisted of flat source and sample foils, separated by 400 μm of vacuum. Upon irradiation by the laser pulse, the Al or Au source foil generates a pulse of $\sim$MeV protons, which is accelerated by target normal sheath acceleration, and traverses the vacuum gap to rapidly heat the full thickness of the Al sample foil. The SOP and CPI probe the rear side of the sample foil. The SOP consisted of an absolutely calibrated optical system imaging the heated sample rear surface through a 470 nm band-pass interference filter and onto the slit of a fast, high dynamic range streak camera. The CPI used a 100 ps linearly chirped pulse as a probe, which reflected off the surface of the heated and expanding sample and was imaged into an interferometer and then onto the slit of a high-resolution spectrometer. With careful calibration of the spectrum and chirp, this diagnostic allowed us to determine the time history of expansion of the heated foil. We compared our data to simulations from a 1-D radiative Lagrangian hydrocode running a variety of widely-used equation of state models, in order to test their validity under our conditions. We found that both the QEOS-based LEOS and SESAME # 3718 equation of state tables agreed with our two measurements within the measurement error of 18%. Although neither could be rejected within error, we found closest agreement with SESAME #3718. We are currently working to compare our data with the more modern SESAME 3719 and 3720 EOS tables.

Stambulchik Evgeny
Progress in line-shape modeling of K-shell transitions in coupled plasmas

E. Stambulchik(1), E. Kroupp(1), D. Osin(1), V. Bernshtam(1), D. Fisher(1), L. Weingarten(1), Y. Maron(1), Yu. Ralchenko(2), I. Uschmann(3), F. Zamponi(3), E. Foerster(3), A. Sengebusch(4), H. Reinholz(4), and G. Roepke(4)

(1)Weizmann Institute of Science, Israel (2)NIST, USA (3)Jena University, Germany (4)University of Rostock, Germany

We will present recent progress in modeling and analysis of X-ray spectra emitted from coupled plasmas. Two distinct environments will be considered: (i) a solid-density strongly coupled plasma formed in short-duration, high-power laser-matter interactions, and (ii) a moderately coupled plasma at the stagnation phase of a mega-ampere z-pinch device. The extreme conditions found in these setups make the task of line-shape modeling highly challenging. A thorough, self-consistent modeling should comprise many different processes and effects, such as strong correlations between the plasma particles, plasma polarization effects, Stark broadening, opacity effects, and influence of possible intense magnetic fields. Detailed collisional-radiative calculations are required when several transitions (e.g., the satellites) blend in.
Presented will be examples of the calculations of the spectra of resonance, inner-shell, and satellite transitions, compared with experimentally obtained data.

Gregori Gianluca
Probing the structure of warm dense matter

G. Gregori (1, 2),B. Barbrel (3), A. Benuzzi-Mounaix (3), C. Brown (4), E. Garcia-Saiz (5), S. H. Glenzer (6), F. Y. Khattak (5), M. Koenig (3), A. Pelka (7), D. Rilley (5), M. Roth (7), C. Spindloe (2), J. Vorberber (8), K. Wünsch (8), D. O. Gericke (8)

(1) Department of Physics, University of Oxford, OX1 3PU, UK (2) CLF, Rutherford Appleton Laboratory, OX11 0QX, UK (3) LULI Ecole Polytechnque, 91128 Palaiseau, France (4) AWE plc., Aldermaston, Reading UK (5) School of Mathematics and Physics, Queen's University, Belfast BT7 1NN, UK (6) Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551, USA (7) TU Darmstadt IKP, D-64289 Darmstadt, Germany (8) Department of Physics, University of Warwick, Coventry CV4 7AL, UK

We have experimentally measured the structure factors of warm and compressed low-Z materials (Li and CH) near the hydrodynamic regime. The experiments have been performed using spectrally and angularly resolved x-ray scattering measurements in a solid density plasmas produced by shock compression with a high power laser. This work been performed at the VULCAN laser facility at the Rutherford Appleton Laboratory (UK) and at the LULI2000 facility at the Ecole Polytechnique (France). Additional laser beams have been then used to create a secondary plasma which generate an intense source of x-ray radiation that is scattered across the sample and observed in a forward scattering geometry and dispersed using a graphite Bragg spectrometer. In addition to the x-ray scattering measurements, the shock properties have been monitored with a dual color VISAR and streaked optical pyrometry, as well as with a XUV flat-field spectrometer. In the forward scattering (i.e., hydrodynamic) regime the scattering cross section becomes sensitive to the degree of ion-ion and electron-ion correlations, thus providing a direct tool to investigate screening effects and the behavior of the equation of state (EOS) in strong coupling conditions. Comparison with hydrocodes is shown in details. The inferred properties of the dense plasma from the scattering data are discussed and detailed comparison with statistical models of strongly coupled plasmas is reported.
This work was partially supported by the Science and Technology Facilities Council of the United Kingdom and by Laserlab funding. The work of SHG was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48 and supported by LDRD 05-ERI-003.

High energy density plasmas - Posters

Gericke Dirk O.
Dynamic Compression of Hydrogen: Probing the High-Pressure Melting Line

A. Grinenko, D.O. Gericke and J. Vorberger
Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, UK

Experimental and theoretical investigations of the thermodynamics and structural properties of hydrogen continue to break new ground. Despite the seemingly simple elementary composition, hydrogen is known to have a variety of complex phases. Moreover, conclusive answers concerning the existence of the plasma phase transition, the nature of the molecular to atomic transition in the high density fluid, the location of the metallization transition in the solid, and the high pressure melting line are still needed.
Here, we investigate the capabilities of dynamic compression by means of intensive heavy ion beams to be carried out at the new FAIR facility at GSI-Darmstadt. The design consists of a hollow cylinder made of lead or another metal filled with frozen hydrogen. The outer absorber is heated by an intense heavy ion beam and its hydrodynamic expansion is finally compressing the hydrogen. For the modelling, we need a wide range equation of state for hydrogen encompassing frozen states to the high-temperature plasmas. Such an EOS has been developed on the basis of first principle simulations and experimental data.
The results of our hydro-simulations indicate that, using the capabilities of the new FAIR facility, it will be possible to access the regions of solid and fluid molecular hydrogen around the maximum of the melting line as well as the metallic fluid region. By carefully tuning the beam parameters, it should be possible to determine the hydrogen melting line in the high-pressure region. Our calculations, also indicate that x-ray scattering can be employed to experimentally verify the melting since the associate structures of the lattice and the fluid are quite distinct.

Iosilevskiy Igor
Non-congruent phase transitions in high energy density plasmas

Igor Iosilevskiy
Moscow Institute of Physics and Technology (State University), Russia

Non-congruent phase transition (NPT) is the most general form of phase coexistence in high-energy-density (HED) plasma mixtures of two or more chemical elements. The basic feature of NPT is their ability to vary chemical composition stoichiometry of coexisting phases with no violation of total stoichiometry of two-phase system. Non-congruence leads to essential change in properties of phase transitions in comparison with standard ones in ordinary substances. Non-congruent phase transformation dynamics is defined as strong dependence of phase transition parameters on the rapidity of the transition, while the NPT thermodynamics is the essential change in properties of two-phase region boundaries including critical point(s). In particular, any pressure-temperature boundary of NPT is no more one-dimensional curve but two-dimensional region instead. Several examples of non-congruent phase transitions are considered. The basic case is non-congruent evaporation in high-temperature uranium-oxygen plasma. The features and parameters this phase transition up to the critical point have been studied thoroughly in frames of nuclear reactor safety problem [1]. The second example is non-congruence of hypothetical 'plasma' and 'dissociative' phase transitions in conditions of mixed plasma in interiors of giant planets, brown dwarfs and extrasolar planets. The third case is non-congruence of fluid-fluid phase transitions in ionic liquids and molten salts. We discuss the difference between real phase transitions in ionic systems and its standard modeling equivalents ('primitive' ionic model and other two-component ionic MC and MD simulations etc.) from the viewpoint of non-congruency. We discuss also improvement of these models, which is needed for correct description of non-congruence. The state and perspectives of other simplified Coulomb models for detailed study of non-congruent fluid-fluid phase transitions are also discussed. Work supported by the RAS Scientific Program "Physics of extreme states of matter".

[1]. Iosilevski I., Hyland G. et al. Int. J. Thermophys. 22 1253 (2001); Ronchi C., Iosilevski I., Yakub E. Equation of State of Uranium Dioxide Springer, 2004, 366 p.

Khishchenko Konstantin
Experimental and Theoretical Study of Aluminum and Silver Plasmas under Femtosecond Laser Pulse Influence on Solid Targets

K. V. Khishchenko, M. E. Veysman, D. S. Sitnikov, M. B. Agranat, N. E. Andreev, S. I. Ashitkov, V. E. Fortov, P. R. Levashov, A. V. Ovchinnikov and M. E. Povarnitsyn
Joint Institute for High Temperatures, Russian Academy of Sciences, Izhorskaya Street 13 Bldg 2, Moscow 125412, Russia

The experimental-theoretical method of study of plasmas created on the surface of aluminum (Al) and silver (Ag) solid targets irradiated by intense femtosecond laser pulses is presented. The method is based on wide-range semiempirical models of optical, transport, and thermodynamic properties of Al and Ag plasmas. Numerical coefficients in these models are chosen so as to ensure the best agreement of calculated and experimental values of complex absorption coefficient of Al and Ag plasmas obtained at ultra-short time scales by means of femtosecond interference microscopy. The hybrid computer code based on these models is elaborated and used for simulation of non-stationary femtosecond laser-produced plasmas. Unexpectedly high values of the phase of the complex reflection coefficient at short (200 fs) time delay between pump and probe laser pulses are obtained for Ag experimentally; possible explanations of this phenomenon are discussed.

Kurilenkov Yuri
On correlation between near threshould absorption spectra and stopping power at strong coupling

Yu. K. Kurilenkov (1) and G. Maynard (2)
(1)Joint Institute for High Temperatures of Russian Academy of Sciences, 13/19 Izhorskaya Str., 125412 Moscow, Russia (2)Laboratoire de Physique des Gaz et des Plasmas, UMR-8578, Bât. 210, Université Paris XI, F-91405 Orsay, France

Analysis of plasma absorption in terms of Kubo-Greenwood formula indicates the key role of density of final electron states (influenced by many-particle electron correlations) near the boundary of discrete and continuum states [1,2]. At high plasma densities the coupling effects in absorption are not recognising properly, meanwhile for moderately dense plasmas these effects are manifested still poorly [3]. Nevertheless, recent progress in experiments represents new opportunities. For example, sophisticated data on X-ray absorption of warm dense aluminum plasma created by ultra-short laser pulse [4] allow clarifying some density effects in spectral opacity. In particular, at the present work we analyze the nature of measured at [4] absorption spectra and some consequences. In fact, besides of "transparency window" –like spectra behavior [1,2] before the edge itself, the "blue" shift of K-edge was registered at experiment also [4]. Approximately, the value of shift turns out proportional to laser intensity. Qualitatively, this effect have been discussed earlier (see fig.1 at [2]) and may represent the manifestation of the "shift" of density of final states due to quiver energy of electrons in laser field. The value of quiver energy is the order of thermal energy at experiment [4], and, correspondingly, it provides the estimated value of K-edge blue shift as 10-15 eV. Next, our present analysis shows that appearance of K-edge "blue" shifts at experiment [4] might be accompanied by enhanced stopping [5] of protons also, that would be interesting to verify in further experiments.

[1] Kobzev G.A.,Kurilenkov Yu.K.,Norman G.A. High Temperature, 15 (1977)163; Transport and Optical Properties of Nonideal Plasmas. Kobzev et al., eds., Plenum Press, New York 1995.
[2] Berkovsky M.A., Kurilenkov et al In: Strongly Coupled Plasmas Physics. Van Horn H. and Ichimaru S., eds., Rochester University Press, 1993, p. 2423.
[3] Vitel Y , T.V.Gavrilova et al. JQSRT), 83 (2004) 387.
[4] L.Lecherbourg, R.Shepherd, P.Audebert et al. High Energy Density Physics 3(2007)175; see also luli.polytechnique.fr/wdm07/
[5] Yu. K. Kurilenkov, G. Maynard et al., Journal of Physics A: Math. And General (IOP), 39 (2006) 4683.

Levai Peter
Viscosity in strongly coupled quark matter

Peter Levai(1), Andras Hazi(1), Peter Hartmann(2), Zoltan Donko(2), Gabor J. Kalman (3)
(1) MTA KFKI RMKI, 29-33 Konkoly Thege Str., Budapest, 1121, Hungary; (2) MTA SZFKI, 29-33 Konkoly Thege Str., Budapest, 1121, Hungary (3) Boston College, Chestnut Hill, MA 02467, USA

The properties of a strongly interacting quark plasma have been investigated in a molecular dynamical simulation. We have focused on the viscosity of the quark plasma and determined it in different scenarios. We have considered non-abelian quark-quark potential, and color rotation mechanism has been introduced. The obtained numerical results will be presented and compared to other theoretical results on QGP viscosity.

Levashov Pavel
Two-temperature semiempirical wide-range equations of state based on average atom model for simulation of laser-matter interaction

Levashov P.R., Obruchkova L.R., Khishchenko K. V.
Institute for High Temperatures RAS, Izhorskaya 13 Bld. 2, Moscow 125412, Russia

We present two-temperature wide-range equations of state for metals consisting of a cold curve, ionic and electronic components. If we neglect phase transitions the ionic component is based upon the simple semiempirical expression which provides for good agreement with static and shock-wave experimental data. For the electronic component in the wide range of pressures and temperatures we use the Hartree model in which the Thomas-Fermi potential is consistent with the electronic density of both bound and free electrons. To ensure this the Shrödinger equation is solved to determine the energy levels and wave functions of bound electrons; free electrons are treated semiclassically.
As we know the self-consistent potential of electrons we can obtain all thermodynamic values; the equilibrium ion mean charge and ionization potentials are determined from the electron density and energy levels of electrons. Ionization potential lowering, temperature and pressure ionization are automatically included into the used average atom model in good agreement with theoretical and experimental data. To accelerate calculations of different parameters for electrons we use interpolation methods.
The two-temperature equation of state can be constructed by the following approximate technique: using given non-equilibrium mean charge and density one can determine the effective chemical potential; to calculate thermodynamic parameters of the system at given density and ion and electron temperatures we use this effective chemical potential and self-consistent electrical potential of the cell.
To take into account phase transitions we use much more complex expression for the ionic component which takes into account melting, evaporation and sublimation. Together with the described above cold and electronic components at the same temperature this equation of state agrees both with experimental data and first-principle calculations up to moderate temperatures and densities. In the case of different temperatures for electrons and ions it is possible to trace the influence of this difference on the position of phase boundaries.
The described equations of state were used for a simulation of femtosecond laser-metal interaction where ionization and non-equilibrium effects can't be neglected; the most interesting results will be presented.
This work is done under the RFBR financial support, grants 06-02-17464, 08-08-01055.

Mulser Peter
Collisional Absorption in Strong Laser Fields

Peter Mulser Ralf Schneider
TQE: Theoretical Quantum Electronics Technical University of Darmstadt Hochschulstr. 6 D-64289 Darmstadt, Germany

Collisional absorption of intense laser beams and stopping of ion beams in plasmas are characterized by large ratios of drift to thermal velocities. Essentially two approaches have been used to solve the problem: the dielectric theory (DT), describing the energy loss by the excitation of plasmons, and the so-called ballistic model (BM [1]), determining the momentum loss of electrons due to collisions with the ions. The advantage of DT is the correct description of Debye shielding, the disadvantage lies in the artificial introduction of a lower cut off. The BM excells by its conceptual simplicity and no need of a lower cut off, shielding however must be introduced by separate considerations. By combining both along ideas outlined in [2] we arrive at a more physical and more appropriate description of collisional laser beam absorption in dense matter. In DT absorption is given in terms of an infinite sum of integrals in momentum space on combinations of complex exponentials and Bessel functions of all orders [3]. As soon as the drift ratio approaches values of the order of 10 more than 1.000 terms (!) must be summed to reach convergence. We show in a first step how the Bessel functions can be avoided by slightly modifying the sinusoidal quiver motion. In a second step we introduce an effective electron-ion collision frequency from which absorption (or stopping) is determined in the standard manner. With the help of the BM we arrive at closed expressions with a generalized Coulomb logarithm lnL. Finally we give an interpretation of saturation of shielding. In laser-plasmas interaction one is frequently faced with the problem that lnL in its standard form becomes negative. For such situations we arrive at appropriate correct expressions. As a byproduct the domains of validity of the concepts of the lengths of Debye, de Broglie and Landau are given in view of applications in warm dense matter physics. Some standard arguments used in this connection are critcally reviewed.

[1] P. Mulser, F. Cornolti, E. Besuelle, and R. Schneider, Phys. Rev. E 63, 016406 (2000).
[2] R. Schneider, Contrib. Plasma Phys. 41, 315 (2001).
[3] D. Kremp, Th. Bornath, M. Bonitz, and M. Schlanges, Phys. Rev. E 60, 4725 (1999).

Murillo Michael
Viscous Damping of Ion-Acoustic Waves in Warm Dense Matter

Michael S. Murillo
Los Alamos National Laboratory

Collisional damping of collective modes in dense plasmas has a long history, and remains an active area of research today. The ion acoustic wave (IAW) is particularly interesting because it can exist over a wide range of frequencies [1], in contrast to the electron plasma wave. At low frequencies, the modes are long-wavelength hydrodynamic modes, whereas, at high frequencies, the modes are short-wavelength elastic modes. Because of this change of behavior throughout the dispersion of the mode, theoretical descriptions are challenging. Such modes are of practical importance, however, because their properties affect, for example, sound speeds that are important for describing shocked materials. In the context of inertial confinement fusion, another important quantity is the viscosity, which affects turbulent mixing of pusher and fuel materials that can spoil ignition. To date, the viscosity of a dense plasma has ever been measured, and theoretical works have only focused on simple models, such as the OCP and Yukawa models. Here, it is proposed that X-ray Thomson scattering (XRTS) might be useful to experimentally obtain the viscosity in the warm dense matter regime (WDM), in addition to basic properties of IAWs. A modified Navier-Stokes model is used to obtain an approximate ion-ion dynamic structure factor that includes viscous damping and satisfies the compressibility sum rule. From this model, predictions can be made for the XRTS spectrum. Important for such a model is a prediction of the WDM viscosity. This is obtained via a mapping of dimensionless WDM parameters onto a Yukawa model [2]; the efficacy of this approach is established by comparisons with data in the liquid metal regime and quantum molecular dynamics results. Predictions for the ion-ion dynamic structure factor are shown for several WDM scenarios. It is shown that XRTS studies of IAWs are very difficult because of the low frequencies of IAWs, but will be possible on next generation light sources.

[1] M. S. Murillo, "Longitudinal Collective Modes of Strongly Coupled Dusty Plasmas at Finite Frequencies and Wavevectors," Phys. Plasmas 7, 33 (2000).
[2] M. S. Murillo, "Viscosity Estimates of Liquid Metals and Warm Dense Matter Using the Yukawa Reference System," High Energy Density Physics 4, 49 (2008).

Novikov Vladimir
Quasizone Model of Matter

Vladimir G. Novikov, Alexander S. Grushin
Keldysh Institute of Applied Mathematics, Miusskaya sq. 4, Moscow, Russia

In the quasizone model the spectrum of plasma at high densities is described by using the concept of quasizone – so called energy band, which allows to treat in the same manner bound states for inner electrons, free states for continuum, and also intermediate electron states with energy close to zero, including resonances. The quasizone is a result of special boundary conditions for wave function – quasi periodical conditions in mean spherical approximation [1]. As a result the electron wave function is presented as an expansion over spherical harmonics – only one for bound state, several for intermediate state and with infinity terms for free state (plane wave). Using the quasizone model and local density approximation for exchange and correlation effects it is possible to obtain the energy spectrum, equation of state and photon absorption coefficients in a wide range of plasma temperature and density. The detailed comparison with other approaches such as average atom model of B.Rozsnyai [2], D.Liberman's model (Inferno) [3] and EOSTA model [4] is fulfilled. The calculation of equation of state for elements from hydrogen to gold is carried out. It is shown, that the quasizone model allows obtaining smooth pressure ionization curves at high densities. The cold and Hugoniot curves are in a good agreement with experiment.

[1] A.F.Nikiforov, V.G.Novikov, V.B.Uvarov, Quantum-Statistical Models of Hot Dense Matter, Birkhauser, 2005.
[2] B.F.Rozsnyai, Phys. Rev. A 5, 1137 (1972).
[3] D.A.Liberman, Phys. Rev. B 20, 4981 (1979).
[4] A.Bar-Shalom, J.Oreg, M.Klapish, JQSRT 99, 35 (2006).

Piron Robin

Variational Average-Atom in quantum plasmas - numerical results

R. Piron(1), T. Blenski(1) and B. Cichocki(2)
(1) DSM/IRAMIS/SPAM, CEA Saclay F-91191 Gif-sur-Yvette Cedex, France (2) Institute of Theoretical Physics, Warsaw University, Hoza 69, 00-681 Warsaw, Poland

We are developing a new model of quantum plasma at local equilibrium in which bound and continuum electrons are treated within the same formalism. Models of screened ions in equilibrium plasmas with quantum all electrons are important in photo-absorption and equation of state calculations. Up to now existing models [1] have not been fully variational. Recently [2,3] a fully variational model respecting the virial theorem has been proposed. In the Thomas-Fermi (TF) approximation it leads naturally to the classical TF ion-in-cell average atom model [4] while in the quantum case it leads to a new quantum average atom in jellium (QAAJ) model. In the QAAJ all variables are variational and the equilibrium is defined by the temperature T, the ion density n_i and the atomic number Z. The mean ionization Z^* i.e. the unknown mean jellium electron density $n_0 = n_i Z^*$ is to be found from a new variational equation $\int d^3r\theta(r-R)V_{el}(r) = 0$ with $V_{el}(r)$ being the self-consistent field electrostatic potential, θ the Heaviside function, and R the Wigner-Seitz (WS) radius. Contrary to [1] the WS sphere in the QAAJ model is not neutral.

We report here our work on a QAAJ code that has relativistic and non-relativistic versions. We calculate the equilibrium in two steps : first we find a family of self-consistent-field (SCF) solutions in the four parameter space T, n_i, Z and n_0 and then look for such that fulfils the variational equation providing the correct n_0. As the most interesting cases correspond to the Warm Dense Matter (WDM) regime we focus our attention on dense ($\sim$ solid density) and relatively cold plasmas ($T \leq 5$ eV). The main problem in such regime comes from the long range Friedel oscillations (FO). In order to treat correctly the FO we developed a new approach to the asymptotic SCF electron density and potential since the asymptotic linear response theory in homogeneous plasmas [5] appeared to be quantitatively insufficient for our purpose.

We will present first results from our code (SCF electron density, potential, ionization) for solid density aluminum plasmas in the WDM regime.

[1] D. A. Liberman, Phys. Rev. B 20, 4981 (1979).
[2] T. Blenski, B. Cichocki, Phys. Rev. E 75, 056402 (2007).
[3] T. Blenski, B. Cichocki, High Energy Density Physics 3, 34 (2007).
[4] R. P. Feyman, N, Metropolis, E. Teller, Phys. Rev. 75, 1561 (1949).
[5] C. Gouedard and C. Deutsch, J. Math. Phys. 19, 1, 32 (1979).

Schlanges Manfred

Ionization Dynamics in Dense Nanoplasmas Irradiated by Intense Laser Fields

Manfred Schlanges(1), Thomas Bornath(2) and Paul Hilse(1)
(1) Institut für Physik, Universität Greifswald, Felix-Hausdorff-Str. 6, 17489 Greifswald, Germany (2) Institut für Physik, Universität Rostock, Universitätsplatz 3, 18051 Rostock, Germany

The interaction of intense laser fields with rare gas and metal clusters is investigated using the nanoplasma model. Motivated by recent experiments special attention is directed on the ionization dynamics [1,2]. The nanoplasma model allows to describe different processes like ionization, heating, and expansion that occure during the laser-cluster interaction by a coupled set of hydrodynamic and rate equations.
The initial plasma in the cluster is created due to tunnel ionization described by the well-known ADK-rates. For the heating rate due to inverse bremsstrahlung, a quantum statistical expression including resonant absorption was used. An important issue of laser-cluster interaction is the creation of a high-density nanoplasma. Here, the influence of correlation effects such as the lowering of the ionization energy on the ionization kinetics is of importance. Using generalized electron impact ionization rates, we found a significant enhancement of the yield of highly charged ions [2]. Our numerical results obtained for dual pulse excitation show a maximum yield for a certain delay between the pulses which confirms the results of experimental investigations [3].
A modern tool in laser experiments is pulse shaping which allows to affect specifically the dynamics of the system. In particular, the yield of highly charged ions can be controlled by pulse shaping [4]. For an understanding of the underlying physical processes in the dynamics of laser-cluster interaction, a theoretical description using a genetic algorithm and basing on the relatively simple nanoplasma model seems to be promising. Our first calculations show a considerable enhancement of the ion yield produced by the optimized laser pulse.
The work was supported by the Deutsche Forschungsgemeinschaft, SFB 652.

[1] Th. Bornath, P. Hilse, M. Schlanges, Contrib. Plasma Phys. 47 (2007) 402.
[2] Th. Bornath, P. Hilse, M. Schlanges, Laser Physics 17 (2007) 591.
[3] Th. Döppner et al., Phys. Rev. 73 (2006) 031202.
[4] N.X. Truong, T. Döppner, Th. Fennel, J. Tiggesbäumker, K.-H. Meiwes-Broer, privat communication.

Sengebusch Andrea
K-line profiles in laser produced dense plasmas

A. Sengebusch, H. Reinholz and G. Röpke
Universität Rostock, Institut für Physik, D-18051 Rostock, Germany

The features of X-ray spectral lines are relevant for diagnostics of warm dense matter. Hence, K-line profiles have been investigated by irradiation of solid targets with intense ultra-short pulse laser beams [1,2]. The emitted K-spectra of sparsely ionized radiators can be used to determine plasma parameters and fields of target regions beneath the laser created hot plasma layer. A theoretical treatment of spectral line profiles on the level of a static plasma potential is applied on mid-Z materials such as silicon, chlorine and titanium. Hartree-Fock-calculations of different ionic configurations verify a blue shift of the emission lines due to excitation and ionization. Calculations of the line profiles within a plasma environment based on a self-consistent ion sphere model show a density, temperature and charge dependent red shift due to plasma polarization. These shifts range up to some eV and appear as an additional line broadening since spectral resolution is often of the same order of magnitude [3]. Moreover, line broadening due to the created electric and magnetic fields within the plasma has to be considered. Investigation of these fields in laser-produced and z-pinch plasmas applying high-resolution X-ray and UV spectroscopy has been performed within a collaboration under the auspices of the German Israeli Project Cooperation Foundation [4]. A more fundamental approach based on a consistent perturbative treatment of the dielectric function within a Green function formalism can describe line shifts as well as line broadening. First results due to this approach are presented.

[1] A. L. Kritcher, P. Neumayer, M. K. Urry, H. Robey, et al.; HEDP 3; 156 (2007).
[2] S. N. Chen, G. Gregori, P. K. Patel, H.-K. Chung, et al.; Phys. Plasmas 14; 102701 (2007).
[3] A. Sengebusch, S. H. Glenzer, H. Reinholz and G. Röpke; Contrib. Plasma Phys. 47; 309 (2007).
[4] Y. Maron, E. Förster, R. Redmer, G. Röpke et al.; German Israeli Project Cooperation Foundation - project number 61280002.

Taccetti Martin
A Technique for measuring the Electron-Ion Temperature Relaxation rate in a Dense Plasma

J.M. Taccetti(1), R.P. Shurter(1), P.M. Goodwin(2), and J. F. Benage(1)
(1)P-24, Los Alamos National Laboratory, Los Alamos, NM USA (2)MPA-CINT, Los Alamos National Laboratory, Los Alamos, NM USA

Current theoretical approaches to temperature relaxation, which can be categorized as binary-collision and many-body approaches, disagree. Existing experimental evidence infers a lower relaxation rate compared to the binary-collision approach, but is insufficient to determine which approach is correct. We present the most recent results from an experiment aimed at obtaining the temperature relaxation rate between ions and electrons in a dense, strongly coupled plasma by directly measuring the temperature of each component. The plasma is formed by heating a gas jet with a 10 ps laser pulse. The electrons are preferentially heated by the short pulse laser ($T_e \sim 100$ eV), while the ions, after undergoing very rapid (sub-ps time-scale) disorder-induced heating, should only reach a temperature of 10-15 eV. This results in a strongly coupled ion plasma with an ion-ion coupling parameter $\gamma_{ii} \sim$ 3-5. We plan to measure the electron and ion temperatures of the resulting plasma independently during and after heating, using collective Thomson scattering for electrons and a high-resolution x-ray spectrometer for the ions (measuring Doppler-broadened absorption lines).

Varentsov Dmitry

Warm Dense Matter Experiments with Intense Heavy Ion Beams at GSI and at FAIR

D.Varentsov, A.Fertman, V.E.Fortov, D.H.H.Hoffmann, A.Hug, M.Kulish, J.Ling, J.Menzel, V.Mintsev, D.Nikolaev, B.Yu.Sharkov, N.Shilkin, V.Ternovoi, V.Turtikov, S.Udrea

Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia Institute of Problems of Chemical Physics (IPCP), Chernogolovka, Russia Institute of Nuclear Physics (IKP), Technische Universität Darmstadt, Germany

Knowledge of basic physical properties of matter under extreme conditions of high energy density, and in particular, of the so-called warm dense matter (WDM), such as equation-of-state, static and dynamic electrical conductivity and opacity is of fundamental importance for various branches of basic and applied physics. Experimental studies of WDM have been traditionally carried out using the most powerful shock wave generators like underground nuclear explosions or powerful lasers. Intense heavy beams provide a unique capability for the WDM research. Using intense ion beams, one can heat macroscopic volumes of matter fairly uniformly and generate this way high-density and high-entropy states. This new approach permits to explore fascinating areas of the phase diagram that are difficult to access by other means. In this report we discuss various physical and technical issues of the high-energy-density physics (HEDP) research with intense heavy ions beams that is being performed at GSI, as well as that is to be carried out at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt. The results of the recent WDM experiments carried out at the HHT area of GSI are presented along with new developments in target and ion-beam diagnostic instruments and methods which will also be used in the future experiments at FAIR.

Zaporoghets Yury

The interaction of explosively driven dense plasma with a low intensity laser radiation

Zaporoghets Yu.B.(1), Mintsev V.B.(1), Gryaznov V.K.(1), Reinholz H.(2), Röpke G.(2), Fortov V.E.(3)
(1) Institute of Problems of Chemical Physics of RAS, 142432, Chernogolovka, Russia (2) FB Physik, University of Rostock, Universitätsplatz 3, D-18051 Rostock, Germany (3) Institute for High Energy Densities of RAS, IHED-IVTAN, Izhorskaya 13/19, Moscow 127412, Russia

The investigation of explosively driven dense plasma using low intensity electromagnetic waves is an important diagnostic tool for studying transport properties of such medium. In particular, physical models describing the behaviour of matter under such conditions can be verified. However, to interpret correctly the results of reflectivity measurements it is necessary to know parameters of a transitive plasma slice. Angular dependence of s- and p-polarized reflectivities at several wavelengths can be used in the integration of corresponding Maxwell equations to construct the spatial profile of the density of charge carriers.
Here, the results of the first experiments on polarized reflectivities of explosively driven dense xenon plasma is presented. The study of polarized reflectivity properties of the plasma was accomplished within the range of plasma densities $\rho = 2 - 3.2$ g/cm^3, pressures up to $P = 18$ GPa and temperatures up to $T = 3 \cdot 10^4$ K under conditions with strong Coulomb interaction (the nonideality parameter up to $\Gamma = 2.0$). We used a dynamic method to generate a strongly non-ideal plasma, based on compression and irreversible heating of the gas in front of a high-power ionizing wave. The variation of density and electron concentrations of the plasma was achieved by changing the initial gas pressure.
To measure the dense xenon plasma polarized reflectivity coefficient, the pulsed $Y_3Al_5O_{12}$:Nd^{3+}+KTP laser system with electro-optical shutter based on DKDP crystal and higher-order mode suppression of the laser radiation was used. For determination of the equilibrium properties of explosively driven plasma, appropriate gas dynamics calculations were carried out. The thermodynamic model of the plasma takes into account Coulomb interaction in frames of Debye approximation in grand canonical ensemble and the short-range repulsion of heavy particles - within the soft spheres model. The integration of Maxwell equations are based on an interpolation formula for dc conductivity, obtained from a systematic quantum statistical treatment of different limiting cases.

Contents

Index