Joint Institute for High Temperatures RAS
Gesellschaft für Schwerionenforschung GSI
Extreme Matter Institute EMMI
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The Seventh International EMMI Workshop on

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The book consists of the abstracts of oral and poster contributions to the Seventh International EMMI Workshop on Plasma Physics with Intense Heavy Ion and Laser Beams at FAIR (December 9–10, 2014, Presidium RAS, Leninsky Avenue 32a, Moscow, Russia).

This workshop is a continuation of serial meetings within the framework of the Memorandum of Understanding signed in November 2008 between Gesellschaft für Schwerionenforschung (GSI), Extreme Matter Institute (EMMI) and Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS) for cooperation in the investigations of extreme states of matter, in particular, accelerator and laser based plasma physics.

The workshop is focused on the research field of intense heavy-ion and laser beams interaction with matter. The main topics include fundamentals of heavy-ion and laser interaction with plasma—status of high-energy-density research; day one experiments with first heavy ion beam parameters at FAIR 2018–2022—fundamental physics of extreme states of matter and diagnostics of relevant processes; plasma physics experimental area—review of technical design reports; joint FAIR-relevant experiments 2015–2018 at the PHELIX-laser, GSI.

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PROTON RADIOGRAPHY OF NONIDEAL EXPLOSIVELY DRIVEN PLASMA OF NOBLE GASES

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For PRIOR experiments we suggest experimental study of EOS of nonideal plasma of noble gases. First experiments in this field was conducted at the TWAC-ITEP proton radiography facility with the compact explosively driven small diameter ($\sim$10 mm) shock tubes with the mass of HE up to 100 g. The shock pressure P in recent argon tests was from 100 to 1000 bars, temperature T was 8–20 kK with non-ideality parameter Γ of about 1. In similar tests with xenon the values of P = 4–6.5 kbar, T = 20–25 kK and Γ = 1–2.5 were reached. However, the observed density gradient in these waves is of the same order as the sensitivity of the technique, so the accuracy of the experiment proved to be low $\sim$20%. Considerably better situation is observed in xenon, where the formation and development of a shock wave and a plasma plug behind its front is firmly registered. Further improvement of the experiments is associated with the using of large scale shock tubes with the mass of HE up to 1.5 kg. The possibilities of PRIOR diagnostics for the investigation of nonideal plasma parameters and comparison with theoretical models are discussed.

CURRENT PLANS FOR HIGH-ENERGY LASER INSTRUMENTATIONS AT FAIR

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The intense heavy-ion beams available at the Facility for Antiproton and Ion Research (FAIR) under construction in Darmstadt, Germany, will enable the creation of large-volume and uniform samples of matter under extreme conditions, which cannot be prepared using other methods like the X-ray FELs or laser-driven implosions. Laser-driven particle and/or radiation sources make it possible to study the thermodynamical properties of these samples that are highly relevant to the physics of planets, the physics of materials under extreme conditions and fusion research.

The flagship tool that will embody the worldwide unique combination of a high-intensity laser and a heavy-ion accelerator is the Helmholtz Beamline project. This laser working at a higher repetition rate than what is currently available opens new possibilities for analysis methods that are being currently used and developed on a single-shot basis at the PHELIX laser facility. The project relies on the construction of a double-beam high-energy multi-kilojoule laser capable of firing at a minute-scale repetition rate. The laser should deliver either programmable nanosecond or short picosecond pulses to the APPA cave.

In a preliminary stage, the APPA cave will be equipped for the starting phase of FAIR with a 100 J sub-nanosecond laser that should be used as a prototype capable of driving some of the experiments of the Helmholtz-Beamline project. In the talk, I will review the parameters and technological bottlenecks that are met by this project.

STUDY OF PHASE TRANSITIONS IN SUBSTANCES UNDER INTENSE HEAVY ION AND LASER INFLUENCES

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Description of the thermodynamic properties of materials in a wide range of parameters is of both fundamental and practical interests. Equations of state for metals over the range from normal conditions to extremely high pressures and temperatures are required for numerical simulations of hydrodynamic processes in condensed media under intense dynamic influences, such as by heavy ion and laser beams.

In this work, a new thermodynamic approach to modeling of equation of state for metals with taking into account the polymorphic transformations, melting and evaporation effects is proposed. Multiphase equations of state for aluminum, tungsten, iron, tin, titanium and some other materials are obtained. Results of calculations for these substances are shown in comparison with experimental data over a wide range of temperatures, pressures and densities. The proposed multiphase equations of state provide for a reliable description of the materials properties over a wide range of thermodynamic parameters. That gives an opportunity for effective use of the equations of state in numerical simulations of unsteady-state hydrodynamic processes at high energy densities.

PRESSURE IN METALS WITH HOT ELECTRONS

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Non-equilibrium two-temperature warm dense metals consist of the ion subsystem that is subjected to structural transitions and involved in the mass transfer, and the electron subsystem that in various pulsed experiments absorbs energy and then evolves together with ions to equilibrium (e.g. [1]). Defenition of pressure in such non-equilibrium systems causes certain controversy (e.g. [2]). In this work we make an attempt to clarify this definition that is vital for proper description of the whole relaxation process. Using the density functional theory we analyze on examples of Al and Au electronic pressure components in warm dense metals. These results allow us to elucidate a way to find a number of free delocalized electrons in warm dense metals.

The work was supported by RFBR grant 14-08-31694.

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REFLECTIVITY, PLASMA FREQUENCY AND CONDUCTIVITY OF WARM DENSE MATTER

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The reflectivity of shocked xenon was measured in the experiments of Mintsev and Zaporoghets in 1989 for wavelength $\lambda = 1064$ nm [1] and further for 694 nm and 532 nm [2]. In [3, 4] the Drude model with collisional frequency in Born approximation, gives reflectivities that are 2.5–3 times larger than the measured values at low densities. The results of other approaches to the collisional frequency calculation also cant́ provide better explanation of steep slope of reflectivity drop with decreasing of density. The assumption of significant width [3, 4] to the shock front gives a good agreement with the experimental data. However, there are no evidences of this effect in experiment. The main goal of experiments [1, 2] was estimation of free electron density in shocked xenon. The absence of adequate theoretical explanation of the experimental results [1, 2] do not allow to obtain consistant estimation for this parameter. We apply method of estimation of plasma frequency and effective electron density, which is based on DFT calculation of dielectric function (DF) and reflectivity. The imaginary part of the DF is evaluated using the longitudinal expression. The real part is obtained by the Kramers-Kronig transformation. The values of plasma frequency calculated in this work are directly associated with the obtained dependencies of reflectivity on density. VASP code is used as in [5]. However as opposed to Desjarlais, the advantage of using of the longitudinal expression is shown. The better agreement with the results for the wavelength 1064 nm [1] is obtained for both absolute values and density dependence. The method of estimation of plasma frequency suggested in this work is also applied for calculation of this parameter for liquid selenium and hydrogen.

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PLASMA PHASE TRANSITION IN THE WARM DENSE HYDROGEN

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First-order phase transition is observed in the warm dense hydrogen at the pulsed-laser heating above the melting line of hydrogen at static pressures in the megabar pressure region by I.Silvera et al (2013). Loubeyre et al (2004) revealed indications to a phase transition by optical reflectance probing at two wavelengths in a laser-driven shock wave in a hydrogen sample, pre-compressed in a diamond anvil cell. The physical nature of the phase transition observed experimentally remains unclear. Different variants are discussed: liquid-liquid, plasma- plasma, molecular dissociation, and even Wigner metallization. Ab initio quantum modeling is applied in this work to elucidate the nature of the phase transition studied. Electron density of states and the characteristic gap in it are investigated. The change of plasma frequency is suggested to be used instead of the degree of ionization to characterize the difference between two phases. Pair distribution function, and conductivity are calculated as well. Arguments are given in favor of the plasma- plasma (fluid-fluid) character of the phase transition discussed. It is shown that Norman-Starostin ideas about (a) plasma phase transition and (b) phase diagram for fluids are not anymore a hypothesis. They are confirmed by the experimental data.

THE RESEARCH OF NONCONGRUENT PHASE TRANSITION PROPERTIES IN COULOMB SYSTEMS BASED ON THE MODEL OF THE BINARY IONIC MIXTURE

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A simple model of Coulomb noncongruent phase transition (NCPT) gas-liquid type with an upper critical point in modified model with no associations [1] of a binary ionic mixture (BIM) on a homogeneous compressible ideal background (or non-ideal) electron gas was built in this work/ BIM ($\sim$) /. In this model, by definition, there is no individual associated groups (complex ions, atoms, molecules, etc.). But it is possible to homogeneously compress both ionic and electronic subsystems. In the case of one ion species this modification is a superposition of correlated only "in average" models OCP of ions and OCP of electrons on the electrostatic compensating background (Double OCP [2]). The analytical approximation (EoS) of Potekhin and Chabrier [3] was used for describing the ion-ion correlations (Coulomb nonideality) in combination with "linear mixture" approximation (LM—Linear Mixing Rule).Ichimaru approximation was used for describing the electron-electron corellations [4]. Phase equilibrium for the charged components was calculated according to the Gibbs-Guggenheim conditions [1], the equality of generalized electrochemical potentials.

Because of the taken simplifications the BIM ($\sim$) model allows to calculate full set of parameters of the phase equilibrium and trace in details features of this noncongruent equilibrium realization in comparison with the simpler (standard) forced-congruent evaporation mode. In particular, in BIM ($\sim$) there were reproduced two-dimensional ("banana-like") structure of two-phase region $P-T$ diagram and the characteristic nonmonotonic shape of caloric phase enthalpy-temperature diagram, similar to those obtained previously in the calculations of the noncongruent evaporation of reactive plasma products in high-temperature heating with the uranium-oxygen system [5]. The characteristic noncongruent evaporation behavior structure contours in the two-phase region (different from the standard isothermal-isobaric crossing regime) was also traced. The parameters of critical points (CP) line were calculated on the entire range of proportions of ions $0 < x < 1$, including two reference values, when CP of noncongruent evaporation coincides with two "end"-points on the boundary of the two-phase region—a point of extreme temperature and extreme pressure, xT and xP . On the $x - T$ diagram there were calculated high-temperature fields of so-called "retrograde" regime of crossing two-phase area with isotherms, isobars and isoentropes. Finally, it is clearly demonstrated the low-temperature property of noncongruent gas-liquid transition—"distillation" , which is weak in chemically reactive plasmas [6] [7], and in contrast, is significant in the exotic realization of noncongruent transition in superdense nuclear matter [8].

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DUSTY AND COLLOIDAL PLASMAS. PHASE DIAGRAMS AND ADDITIONAL SPLITTINGS OF MELTING CURVES

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Noncongruence and phase diagrams of dusty and colloidal plasmas are under discussion.Two simplified variants of a dusty and colloidal plasmas models are considered as a thermodynamically equilibrium combinations of classical Coulomb particles: a two-component electroneutral system of macro- and microions (+Z,-1) and a three-component electroneutral mixture of macroions and two kinds of microions (+Z,-1,+1), Z>>1. The base for a consideration is the well-known phase diagram of dusty plasma [1] for an equilibrium charged system with the Yukawa potential in its standard representation in the coordinates Γ -κ (Γ is the Coulomb non-ideality parameter, κ is the dimensionless Debye screening parameter). The phase regions for the three states of the system (fluid vs. bcc and fcc crystals) from the Hamaguchi diagram are reconstructed in the density-temperature coordinates. The resulting phase diagram in the logarithmic coordinates lnT-ln(n_z) has the form of a linear combination of crystalline and fluid zones separated by the boundaries Γ =const. Parameters and locations of these zones are analyzed in dependence on the intrinsic parameter of the model—macroion charge number Z. Parameters of a splitting the one-dimentional melting boundaries of the Hamaguchi diagram (i.e. hypothetical melting density gap between separate freezing liquid line (liquidus) and melting crystal line (solidus)) are discussed. Made an estimation of a density gap value based on an analogy with a Soft Spheres system. Additional splitting of all phase boundaries in the three-component model (+Z,-1,+1) because of non-congruency of all phase transitions in this model is discussed also.

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FEMTOSECOND LASER ABLATION: THREE-DIMENSIONAL EFFECTS

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Spatial structures of ablative mass flow produced by femtosecond laser pulses with different sizes of focal spot are studied. In experiments with a thick gold film the Ti:sapp laser pulse with a focal size of 100 microns was used, while a soft X-ray probe pulse (photon energy 90 eV) was utilized for diagnostics. The experimental data are compared with simulated mass flows obtained by two-temperature hydrodynamics and molecular dynamics methods.

It is shown that a pulse with much smaller focal size of 0.1-1 micron leads to very different structure of mass flow in very thin gold film with thickness of several tens nanometers lying on glass. Our simulations reveal a new mechanism of evolution of such films. We demonstrate that the irradiated film in the form of flying cupola can tore away from the substrate. Motion of the cupola can ends in either return to substrate, or freezing of the cupola, or else formation of the frozen cupola with a jet or a hole on the top. All these scenarios are determined by four processes: (1) melting of film within an irradiated spot; (2) tearing of molten film from substrate and formation of the flying cupola; (3) mass flow to the top of cupola generated by capillary deceleration; and (4) hardening of the cupola as a result of its cooling followed by recrystallization in flight.

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A TWO-TEMPERATURE MODEL FOR ATOMISTIC SIMULATIONS OF LASER ABLATION AND ION TRACKS

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In this work the atomistic model with two-temperature (2T) relaxation is developed. The model is applied to the simulations of metal surface modifications by femtosecond laser pulses and to the simulations of swift heavy ion (SHI) interaction with matter. The results are obtained for various atomistic models with different scales: from pseudo-one-dimensional to full-scale three-dimensional atomistic simulation.

In the 2T simulations, the free electrons are treated separately as a continuum medium using the heat equation and the ions are treated via classical molecular dynamics, with heat exchange between these subsystems. The basic equation for the electron energy relaxation in this model is as follows:

$$C_e(T_e)\frac{\partial T_e}{\partial t} = \nabla(\kappa_e \nabla T_e) - \xi(T_e, T_i),$$

where the source term $\xi(T_e, T_i)$ corresponds to the energy transfer between electronic and ionic subsystems. The equations of motion for ions are modified to account for the electron-ion energy exchange:

$$m_j \frac{d\boldsymbol{v}_j}{dt} = -\nabla_j U(r_1, ...r_n) + \boldsymbol{F}_j^{lang}(T_e - T_i) - \frac{\nabla P_e}{n_i}$$

where m_j and $\boldsymbol{v}_j$ are the mass and velocity of the j-th atom, $U(r_j)$ is potential energy of the system which is described by the potential, ∇_j denotes differentiation with respect to the coordinates of the j-th atom, $\boldsymbol{F}^{lang}$ is the random force (Langevin thermostat) due to electron-phonon coupling. The last term is the electron blast force of the electron pressure P_e and n_i is the ion density.

The damping time parameter of Langevin thermostat depends on local ionic and electronic temperatures.

The surface modification after laser irradiation can be caused by ablation and melting. At low energy of laser pulse, the nanoscale ripples on surface may be induced by the melting without laser ablation. The nanoscale changes of the surface are due to the splash of molten metal under temperature gradient. The ablation process occurs at a higher pulse energy when a crater is formed on the surface. There are essential differences between Al ablation and Au ablation. The swelling and voids formation as the first step at the shock-wave-induced ablation is obtained for both metals. However the simulation of ablation in gold shows the existence of additional nonthermal ablation which is associated with electron pressure relaxation. This ablation takes place at surface layer in depth about several nanometers and does not induce swelling.

SHI track formation was studied for metals and uranium dioxide. For the SHI simulations, the initial electronic temperature profile was set and the relaxation was studied. It is shown that the main mechanism for track formation in the bulk material is melting and recrystallization, which leads to localized area of high defect concentration. Near the surface, the track formation mechanism changes. The molten material splashes out due to the electron blast force and produces features on the surface. In some sense this mechanism is close to nonthermal laser ablation. The developed model demonstrates that the surface track is a stronger modification of matter than bulk track. The threshold values of stopping power for both types of modification are close but the modification size is larger for surface tracks.

LASER-ASSISTED GENERATION OF GIGAGAUSS SCALE QUASISTATIC MAGNETIC FIELD

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Generation of intense magnetic fields in laboratory attracts much interest as it may be used in various of applications, such as astrophysical studies, Inertial Confinement Fusion (ICF) schemes, magnetic field interaction with atoms and particles, etc. For the laboratory production of magnetic fields of the order of hundreds of kilo-Gauss, pulsed magnetic sources can be used. Modern laser facilities provide possibilities for the one-shot generation of intense magnetic fields up to tens of Mega-Gauss (see, i.e. [1–3]), in a volume of ~ 1 mm^3 and in a time scale of several ns. As we show, an intense laser pulse, combined with a special geometry of a target, may allow to generate sub-Giga-Gauss magnetic fields in a quasistatic regime, though in a smaller spacial size of $\sim 10^{-3}$–10^{-4} mm^3 [4]. A simple setup, which we present, is based on the generation of strong electron currents with a predefined geometry in a curved 'escargot'-like target. Particle-In-Cell simulations and qualitative estimates show that Giga-Gauss scale magnetic fields may be achieved with existent laser facilities. The described mechanism of the strong magnetic field generation may be useful in a wide range of applications, from laboratory astrophysics to magnetized ICF schemes. The geometry and the strength of the described magnetic fields may be interesting for the control of ion and electron beams.

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TARGET EXPLOSION AND REACTOR CHAMBER RESPONSE FOR FAST IGNITION HEAVY ION FUSION

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The concept [1] of fast ignition with heavy ion beams based on a cylindrical target composed of DT-fuel and lead shell and illuminated with an annular compression beam and a circular ignition beam is considered. The total energy of two bismuth beams amounts to 9.4 MJ and the target output is 740 MJ. The target compression and burn is computed by the DEIRA-4 code [2] based on one-fluid three-temperature hydrodynamics with diffusion of radiation and fast fusion ions, nuclear reaction kinetics, heating rates by neutrons and fast beam ions. The equation of state approximates realistic properties of lead and hydrogen in the region of strong coupling.

The target explodes in a spherical reactor chamber of 5 m in radius, with the first wall protected by a 2-mm liquid lead film. The hydrodynamics of fireball expansion and evaporation of the liquid film are computed by two-temperature 1D RAMPHY code [3]. In spherical geometry the volumetric X-ray energy deposition in the chamber filling gas and the liquid film is described in terms of the Rosseland absorption coefficient. Relaxation between matter and radiation temperatures is modeled by using the spectral coefficient of radiative absorption. The neutron energy deposition is determined by means of a general Monte Carlo code for the neutron transport.

The data on the target compression and burn dynamics are presented. In 9ns after the thermonuclear flare the shock emerges at the target surface and a sharp X-ray pulse is generated. The main X-ray flux starts at 300 ns. Propagation of the fireball shock and expansion of the evaporated film in the chamber are analyzed. The fireball expands with the velocity of 400km/s and impacts the evaporated lead layer in 0.01 ms.

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HIGH CURRENT DISCHARGE IN HIGH DENSITY GAS

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Phenomena arising from the interaction of intense energy fluxes with matter, properties of matter under extreme conditions at high pressures and temperatures are very challenging diagnostic task. Powerful gas discharge at high and super-high pressures is a part of high energy density physics and extreme state matter physics. The discharge can be used as a laboratory model of astrophysical objects for modeling radiative transport in star photosphere, equations of state for matter, shock wave propagation in plasma, etc.

Basic difficulties of diagnostics of the discharge with such parameters are connected with the high density of plasma. High energy input into closed volume under high pressure adds technical problems for diagnostics. Optical methods give information only about peripheral areas of the discharge because of the strong absorption of radiation from the central area. We have developed original high-speed diagnostic methods in the optical and x-ray regions, which allowed us to see the discharge channel structure. Also it has been designed contact methods for measure magnetic and electric fields in the discharge channel.

In the report research results for discharge, initiated by wire explosion, in hydrogen at high initial initial pressures of 1–200 MPa and current amplitudes up to 1.5 MA are presented. The phenomena are discussed, which are determined by high density of the gas surrounding the discharge channel: drop in channel brightness with gas density increase and energy input into volume; structure of the discharge channel surrounded by dense gas; x-ray radiation modulation from discharge channel by acoustic oscillations in discharge chamber volume and the channel oscillations connected with alignment of the gas-kinetic pressure and the magnetic pressure.

NUMERICAL ANALYSIS OF ANOMALOUS WAVE PROCESSES AT QUARK-HADRON PHASE TRANSITION

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The paper is devoted to the hydrodynamic description of the collective phenomena occurring at the collision of ultrarelativistic heavy ions and the expansion of quark-gluon plasma (QGP) cloud (so-called fireball). These high energy processes happen at extremely low background density of the baryon charge that imposes special demands on the the numerical model used. The relativistic hydrodynamic codes permitting to simulate flows with regions with essentially lower density have been elaborated on the base of the HLLC method [1]. The equation of state of subhadronic matter describing the quark-hadronic phase transition has been calculated using the MIT-bag model variant [2]. It has been shown that the Taub adiabats passing through mixed phase have segments with an ambiguous representation of the shock discontinuity. The ambiguity is due to the implementation of the shock instability condition $L < 1$. Shocks belonging to such the segments split with formation of a composite compression wave (here two-wave structure). The thermodynamic condition $(\partial^2 p/\partial \tau^2)_S < 0$ can be performed in the transition region and the appearance of rarefaction shocks or composite rarefaction waves is expected. Such the behavior of shock and rarefaction waves is typical for the media with the phase transition of the first order. The results of calculations have completely confirmed the predictions of the theoretical analysis. Besides, it has been found that for the EOS used the velocities of the precursor shock in hadronic phase and the shock wave of phase transition differ very slightly. Taking into account extremely short time of the interaction, the shock splitting may be masked by viscid and nonequilibrium effects. It makes very difficult to identify this phenomenon in collision events. It has been else found that the neutral stability condition is fulfilled only for shocks with the final state in the mixed phase. However, these shocks are unstable with respect to splitting and are not realized as unique wave. Thus, only the phase transition shocks being a part of the composite compression wave may be neutrally stable.

On the other hand, the collective phenomena in the expanding QGP cloud seems to be a marker of the reverse phase transition from the QGP to the hadronic state. The simulation of this process has been carried out in one- and two-dimensional formulations. In the latter case the central and peripheral collisions of nuclei were considered. The fireball expansion after the peripheral collision was modeled in the cylindrical and spherical coordinate systems. It has been found that in all cases the initial stage of the fireball expansion is characterized by the formation of the composite rarefaction wave including the plateau with practically zero gradients. In the one-dimensional case this plateau corresponds to the thermodynamic state on the binodal of the quark-hadron phase transition. Due to spatial expansion of the fireball in the two-dimensional formulations the plateau is the region of mixed states. In all cases the plateau exists during time $\approx 1R_0/c$, where R_0 is the fireball radius, c is the velocity of light. A similar effect with the plateau formation and the same existance duration occurs after the reflection of the rarefaction wave from the centre. In this region the final transition to the hadronic phase is realized. Thus, the complete phase transition from the QGP to the hadronic phase lasts $\approx 2R_0/c$.

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OPTICAL PROPERTIES OF HOT ALUMINUM PLASMAS IN WIDE FREQUENCY RANGE

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Optical properties of hot aluminum plasmas for wide range of densities and temperatures above 10 eV is calculated for wide range of frequencies of laser radiation (from infrared to ultraviolet ones) on the base of quantum statistical approach [1, 2].

For frequences lower than plasma frequency and moderate values of the parameter of coupling the results obtained are in good agreement with ones obtained on the base of kinetic theory [3–5]. Particularly, use of Gould deWitte approach for calculation of the 1-moment correlation function and Screened Born approximation for calculation of renormalization factor [1, 2] ensure results almost identical with ones obtained with wide-range kinetic model for optical frequencies and temperatures above 50 eV.

For large values of laser frequency the connection with bremstruhlang and asymptotic formulas are discussed.

Unlike kinetic theory, the quantum statistical approach permits one to consider consistently dynamical conductivity (or permittivity) of plasmas in wide range of frequencies domain and take into account effects of electrons and ions correlations, static and dynamical screening and strong collisions. The influence of these processes and also of electron-electron collisions on the dynamical conductivity of aluminum plasmas is discussed.

Also the role of i) ions correlations and ii) modification of ion potential screening by core electrons in plasmas with complex ions is studded by means of i) simple analytical formula for ion-ion structure factor [6, 7] and ii) screening function for empty-core pseudo potential [8].

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CONTROLLING THE SPECTRAL SHAPE OF NONLINEAR THOMSON SCATTERING WITH PROPER LASER CHIRPING

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Effects of nonlinearity in Thomson scattering of a high intensity laser pulse from electrons are analyzed. Analytic expressions for laser pulse shaping in amplitude and frequency are obtained which control spectrum broadening for arbitrarily high laser pulse intensities. These analytic solutions allow prediction of the spectral form and required laser parameters to avoid broadening. The predictions are validated by numerical calculations. This control over the scattered radiation bandwidth allows of narrow bandwidth sources to be produced using high scattering intensities, which in turn greatly improves scattering yield for future x- and gamma-ray sources.

1D MODEL FOR INDIRECT TARGET COMPRESSION UNDER CONDITIONS CLOSE TO THE NIF LASER FACILITY

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A one-dimensional model for indirect target compression is proposed, which corresponds to the compression conditions of NIF facility, and allows one to analyze the experimental results. The model reproduces the known from literature data on the measured radiation temperature in the cavity and the shell motion velocity. The model is based on the RADIAN code. 1D program can reproduce main parameters of indirect drive implosion: radiative temperature, r–t diagram, implosion velocity, temperature, and density in different parts of the plasma. Shape of laser pulses (high-foot and low-foot) has influence on the implosion parameters (velocity, density, temperature, pressure). Restriction of this code is connected with impossibility of inclusion into 1D simulation the detailed information about experimental conditions.

HYDRODYNAMIC MOTION IN QUARTZ OPTICAL FIBER UNDER INTENSE LASER ACTION

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This work continues the study of detonation-like mode of laser induced damage propagation. Generally laser induced damage movement can be divided into burning and detonation-like mode. Both modes are characterized by the presence of a moving zone of absorption of laser radiation — brightly glowing plasma and accompanied by the destruction of the fiber. Detonation-like mode is two orders of magnitude faster than known published data on burning fiber glass. The condition of optical fiber and enough long laser pulse let us obtain laser induced damage propagation passing near hundred own core diameters during pulse. The using as target the core of silica-based optical fiber has some diagnostic advantages. It allows spatially splits "start" and "stop" points and to supply the same form of energy deposition in every cross section of optical fiber. Tested regime demonstrates near constant velocities during 250 ns in the range of laser intensity 2–4.5 GW/cm^2.

For the first time the channels formed in the silica fibers core were investigated by optical and scanning electron microscopes. This allowed us to measure the area of crushability and zones of the "start" and "stop" in the saved silica fibers after of detonation-like mode propagation.

NUMERICAL MODELING FAIR ONE DAY EXPERIMENTS

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We present results of 3d numerical modelling of experiments on investigating thermopysical and transport properties of matter induced by intense beams of heavy ions in metals. These calculations support different experimental setups of heavy-ion heating and expansion with beam parameters corresponding to FAIR one day experiment. We present the physical domain on the phase diagram that will be accessed with revised beam parameters and discuss possibilities of future experiments.

PROBLEM OF HIGH-TEMPERATURE PHASE DIAGRAM AND CRITICAL POINT PARAMETERS IN SILICA AS PERSPECTIVE MATERIAL FOR EXPERIMENT-1 AT FAIR

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Great uncertainty in our knowledge for high-temperature phase diagram and location and properties of critical point in silica (SiO_2) are under discussion as extra-important for key material in very many applications, such as so-called catastrophic fuse effect in optical SiO_2 fibers, catastrophic historical bombarding of the Earth and other planets, natural or artificial bombarding of the Moon, the problem of chemistry of Earth's earliest atmosphere etc. Experimental data are scanty, while existing theoretical predictions are contradictory. We compare thermal and caloric phase diagrams of SiO_2 in ρ -T; H-T and P-T planes and examine them as being predicted via different theoretical approaches, i.e. traditional quasi-chemical representation (code SAHA-IV [1]), improved wide-range semi-empirical EOS (MPQEOS [2]), direct numerical simulation via ionic molecular dynamic (IMD) [3] and ab initio DFT/MD approach [4]. We compare theoretical predictions with handbook recommendations [5] and experimental data on equilibrium vapor composition over the boiling SiO_2 [6]. We discuss validity of traditional semi-empirical rules, which are widely used in estimating of critical points parameters, such as the "rectilinear diameter rule", so-called Guggenheim formula for ρ -T phase boundary and Timmermans rule for critical compressibility factor etc. We test applicability for SiO_2 [7] for new version of the rule of rectilinear diameter, which was identified previously by the Coulomb model [8] for spinodal compressibility factor. We discuss hypothetical *non-congruence* of gas-liquid phase transition in SiO_2 as accessible material for modeling of non-congruent evaporation in uranium dioxide [1, 9]. Perspectives of resolution for the problem of SiO_2 phase diagram and critical point location are discussed in their application to future experiments at FAIR in frames of idea of quasi-isobaric volumetric heating of highly dispersed porous [10] or extra-thin foil materials [2].

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STUDY OF NEAR-CRITICAL STATES OF REFRACTORY MATERIALS BY INTENSE HEAVY ION BEAMS

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Thermodynamic and transport properties of matter in the vicinity of phase boundary and critical point of liquid-vapor transition such are of fundamental interest to many branches of basic physics, such as physics of warm dense matter (WDM) and strongly coupled plasmas, atomic physics and astrophysics. Investigation of these properties has numerous practical applications, including inertial fusion, high-temperature material processing, spacecraft meteoroid protection and safety of nuclear power plants. Wide-range semi-empirical EOS models are mostly used in this region of the phase diagram, however any reliable experimental data are of great interest. For example, the critical point parameters (pressure, density and temperature) still remain unknown for most of metals and many other refractory materials. Intense heavy ion beams provide a unique capability to research this important region of phase diagram. Employing a heavy ion beam which will be available at FAIR one can heat macroscopic volumes of matter fairly uniformly. The evaporated target material can also get to a strongly coupled plasma state while expanding and impacting on a hard material (sapphire) window. The details of experiments on heavy ion heating and expansion of refractory materials will be discussed. Also, the results of a preliminary simulations of phase trajectories that can be obtained with promised FAIR uranium beam will be presented. For these simulations, a one-dimensional hydrodynamic code and a wide-range semi-empiric EOS were used, and Copper was taken as the target material.

PROTON RADIOGRAPHIC STUDIES OF PHASE TRANSITIONS IN COMPRESSED PLANETARY LIQUIDS

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Properties of molecular liquids, such as nitrogen, hydrogen and hydrogen-helium mixtures at very high pressures and densities are one of the fundamental problems of modern physics. The understanding of interiors and magnetic fields of giant planets are strongly affected by proposed plasma phase transitions in liquid gases, accompanied by increase of density and electrical conductivity. It is possible to reach such states on phase diagram by multiple shock compression of sample between two head-on impactors, or between single impactor and static anvil. In first case, thermodynamic states of high interest, close to planetary isentropes can be reached, although proper diagnostics is near impossible. Proton radiography setup, PRIOR, offers unique capability of direct measurements of density in such experiments.

In the talk, issues concerning possibility of fitting of promising double-impactor experiments in existing and future explosion protection chambers of PRIOR will be discussed, along with results on proton radiography of multiple shock-compressed polymer, obtained in experiments at PUMA setup in ITEP, Moscow.

CRYOGENIC TARGETS FOR THE LAPLAS EXPERIMENTS: FABRICATION, MANIPULATION AND SURVIVAL STUDY

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HEDgeHOB collaboration plans to carry out a set of experiments at the FAIR facility at Darmstadt in the field of High Energy Density (HED) matter generated by heavy ion beams. One line of research has been named, LAPLAS (LAboratory PLAnatory Science) [1]. This scheme proposes low-entropy compression of a material like frozen hydrogen or deuterium ice that is enclosed in a cylindrical shell of a high-Z material like gold or lead. Such type of experiment is suitable for studying the problem of hydrogen metallization or for creating physical conditions that are expected to exist in the interiors of the giant planets. This report discuss different possible approaches to preparation of cylindrical cryogenic targets to the LAPLAS experiments [2]. The research has been carried out in the area of target fabrication, target manipulation, and target survival. On the basis of the performed research, the technical requirements to the corresponding specialized cryogenic system (SCS) were defined. The SCS conception is proposed aiming the potential risks minimization during the system designing and functioning.

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HIGH FIELD PHYSICS POSSIBILITIES AT THE HESR

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As a novel and unique possibility for research in ultra-high field science, the HESR [1] will provide brilliant intense stored ion pulses at relativistic velocities up to $\Gamma = 6$. The physics of extreme atomic systems can uniquely be studied be means of such heavy highly charged ions [2]. These are true 'few-electron systems' (1–4 electrons), strongly bound to a heavy nucleus, and thus ideal candidates for a direct comparison between state-of-the-art atomic structure calculations and high-precision measurements. When such ion beams interact with counter-propagating laser pulses, exciting physics experiments can be performed. The ions namely 'see' the laser frequency to be Doppler shifted by more than one order of magnitude. In addition, the relativistic Doppler-effect will also shorten the counter-propagating laser pulse, in total boosting the power density by more than 2 orders of magnitude. This, in addition, will allow for completely new possibilities to reach ultra-high field strength in the interaction between the stored ions and laser pulses.

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DEBRIS PROTECTION OF VACUUM TARGET CHAMBER FOR PLASMA EXPERIMENTS AT FAIR

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Recently Technical Design Report on design of vacuum target chamber for plasma experiments at FAIR was prepared. Details of debris protection of vacuum target chamber are presented in this report. Technical and physical issues of protection of optical and entrance ports are discussed. Possible solutions are analyzed.

VISAR SYSTEMS FOR FAIR

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Pulsed volumetric heating by ion beams or local heating by laser radiation creates shock waves in matter. Study of their passage through the substance provides valuable information about the material characteristics and their behavior under extreme conditions. VISAR type interferometric systems are basic in the study of powerful shock waves passing through matter. Modification of VISAR, called Line imaging interferometer, allows registration of shock wave speed in transparent media and the motion of opaque media surface with spatial (10 microns) and time (10 ps) resolution.

Based on the experience of developing and using of various VISAR type systems, analysis of the critical points in developing of speed measuring system for FAIR is presented. Basic technical requirements formulated and appropriate technical solutions proposed.

PRIOR PROTON MICROSCOPE (DEVELOPMENT AND COMMISSIONING)

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The prototype of PRIOR (Proton microscope for FAIR) facility was developed at SIS-18 accelerator at GSI (Darmstadt, Germany). PRIOR setup is designed for measurement, with high spatial resolution up to 10 mkm, of density distribution of static and dynamic objects by using a proton beam with energy up to 4.5 GeV. PRIOR will be a key diagnostic instrument for HED research program of HEDgeHOB collaboration at FAIR. Static commissioning with static objects with 3.6 Gev protons, was demonstrated a spatial resolution of 30 mkm. Dynamic commissioning was performed with target based on underwater electrical wires explosion with electrical pulse with current amplitude of ∼200 kA and rise time of 2–3 microseconds.

THE RF SYSTEM FOR HOLLOW HEAVY IONS BEAM FORMATION

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The new method for investigation of high energy density states in matter, which based on irradiation of combined target by hollow high energy heavy ion beam was proposed in the Institute for Theoretical and Experimental Physics (ITEP). The experiment of high energy density states generation will be carry out in framework of FAIR project. The RF deflecting system (Wobbler) for formation of hollow high energy heavy ion beam with kinetic energy $W = 1$ GeV/n is developed at ITEP.

A LIGHT GAS DRIVER FOR MATTER PROPERTIES STUDIES AT FAIR

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At the Technische Universität Darmstadt the design and realisation of a two stage light gas driver for flyer acceleration is ongoing. The first stage consists of four pistons driven by methane combustion. These pistons compress and heat up Helium in the second stage. The Helium then is supposed to accelerate a sabot carrying a flyer.

According to present estimations the two stage device could accelerate 3 g loads up to about 3 km/s. The flyers will shock load different types of targets. The resulting material states should be investigated by a combination of proton radiography and other means. For proton radiography the use of the proton microscope PRIOR at FAIR is envisaged.

JOINT FAIR RELEVANT EXPERIMENTS 2015–2018 AT THE PHELIX-LASER, GSI

STATUS OF THE PHELIX FACILITY AND RECENT DEVELOPMENTS ON TEMPORAL CONTRAST CONTROL

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This presentation will give an overview of the state of the art of the PHELIX laser facility at GSI as well as the latest developments regarding the temporal contrast of the PHELIX short pulse. A new contrast-boosting module based on an ultrafast optical parametric amplifier (uOPA) has been developed and recently been installed into the PHELIX short pulse system. Thanks to the parametric nature of the amplification process and to the short pump pulse duration on the order of one picosecond, this module is capable of producing a temporally clean pulse at the 100 microjoule level. Injecting this pulse into the PHELIX amplification chain results in a level of amplified spontaneous emission (ASE) as low as 10^{-11} which is an improvement of more than 4 orders of magnitude compared to the standard configuration. In addition, by proper tuning the gain between the uOPA and the subsequent amplifiers, the ASE-level can be adjusted between the typical 10^{-6} and the optimal 10^{-11}. This is very favourable for a user laser facility which is provides beamtime for various experiments with different demands on the ASE-contrast.

FIRST HED-EXPERIMENTS AT THE FAIR-FACILITY: FROM IDEAS TO EXPERIMENTAL RESULTS

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The Plasma Physics Community was asked to draw up the physical case for first experiments at the FAIR-acceleration facility. The specific energy deposition at the initial U-beam parameters will reach 1–10 kJ/g. This will allow creation of HED-matter with sub eV temperature at near solid density and corresponding kbars pressure and investigation of e.g. two phase liquid–vapor region or CP for variety of materials and composites.

Currently, HEDgeHOB and WDM collaborations are developing proposals for Day-One experiments using available theoretical capabilities. Experimental realization of these proposals demands strong involvement of experimental groups from IPCP RAS, JIHT RAS, ITEP, MEPhI and other institutions in order to develop diagnostic sets which will provide measurements with required for EOS precision.

In the talk short overview of the initial U-beam parameters and first proposals for Day-One experiments will be given.

THEORETICAL SUPPORT OF LASER EXPERIMENTS

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Theoretical research in the Joint Institute for High Temperature of RAS on the intense laser interaction with matter is discussed in view of current and future experiments, in particular with PHELIX at GSI-FAIR, Darmstadt.

Wide-range models elaborated in JIHT RAS are used for the description of material response on the intense laser action. Comparison of experimental findings with the results of simulation is used both for the numerical model verification and for estimations of the interaction parameters that cannot be measured directly in experiments.

Electron acceleration mechanisms are discussed and analysis of the experimental data on X-ray generation at relativistic laser intensities is presented. Generation of energetic electron bunches in the laser interaction with low-density targets, and with pre-plasma created by laser pre-pulses at grazing incidence to solid targets is under discussion.

The theoretical support of laser-matter experiments and optimization of secondary sources of high-energy particles and photons for warm dens matter diagnostics are considered.

WIDE-RANGE MODELS FOR HYDRODYNAMIC SIMULATION OF LASER EXPERIMENTS: CURRENT STATUS AND PERSPECTIVES

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To analyze the multi-stage dynamics of targets irradiated by laser pulses we use a 1D wide-range two-temperature hydrodynamic model, which correctly describes laser energy absorption, electron-ion coupling, electron thermal conductivity and radiation transport, starting simulation from the normal solid density at room temperature. In future, we plan the model extension on 2D and 3D geometry to cover a wide variety of actual problems of laser-matter interaction.

PRE PULSE CONTROLLED ELECTRON ACCELERATION FROM TENUOUS PLASMA BY RELATIVISTIC LASER PULSE

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Plasma created by a relativistically intense femtosecond laser pulse can be used as a brilliant source of ultra-short bursts of high energy photons in X- ray and γ-ray diapasons. Besides of the laser pulse intensity, its duration and temporal structure (pre-pulses, leading edge sharpness, ASE level and duration) determine pre-plasma scale and length, that in its turn give rise to the different acceleration mechanisms. In this paper we present experimental results and numerical 3D PIC simulations on hard x-ray and gamma-emission from plasma created by the ultrashort relativistic laser pulse. We varied its intensity, duration and contrast to reveal key electron acceleration mechanisms and to optimize the photon yield for different applications.

We used Ti:Sapphire laser system, which generates femtosecond pulses (40fs, 100mJ, 10Hz) of relativistic intensity (up to $10^{19} W/cm^2$). Different laser pulse contrasts were used from 10^{-5} to better than 10^{-10}. Pulse duration was changed by the grating compressor detuning. To create an artificial pre-pulse sliced ultrashort pulse, uncompressed pulse or long 13 ns pulse from the external active mode-locked Nd:YAG laser was used. The pre-pulse intensity of the target was also adjusted to control pre-plasma characteristics. Numerical simulations were done using fully relativistic 3D PIC code Mandor.

HIGH-RESOLUTION X-RAY SPECTROMICROSCOPY DIAGNOSTICS OF PLASMA PRODUCED BY HIGH CONTRAST FEMTOSECOND LASER PULSE IRRADIATION OF SUBMICRON CLUSTERS

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The interaction of ultra-short, ultra-intense laser pulses with structured targets, such as clusters, exhibits unique features, stemming from the enhanced absorption of the incident laser light compared to solid targets. Due to the increased absorption, these targets are heated significantly, leading to enhanced emission of x-rays in the keV–MeV range and generation of electrons and multiple charged ions with kinetic energies from tens of keV to tens of MeV.

An overview of recent experimental and theoretical results, obtained by high-intense ultra-short Ti:Sa laser pulse interaction with different submicron clusters media, will be presented. High-resolution K- and L-shell x-ray spectra of plasma generated by ultra-intense laser irradiation of submicron-sized CO_2, Ar, Kr, Xe clusters have been measured with intensity 10^{17}–10^{19} W/cm^2 and a pulse duration of 30–1000 fs. X-ray spectral methods have been proposed to determine the parameters of the plasma formed at the early stages of its evolution. It has been shown that the spectra of hollow ions are the most informative in the first moments of the heating of a cluster, whereas the diagnostics of the late stages can be performed using the conventional lines of multicharged ions. It is found that hot electrons produced by high contrast laser pulses allow the isochoric heating of clusters and shift the ion balance toward the higher charge states, which enhances both the X-ray line yield and the ion kinetic energy. Results of experiments dealing with a femtosecond laser-driven cluster-based plasma allowed by analyzing the laser satellites of spectral lines of Ar XVII to reveal the nonlinear phenomenon of the generation of the second harmonic of the laser frequency.

GENERATION OF K_α X-RAYS IN THE INTERACTION OF FEMTOSECOND LASER PULSES WITH THE NANOSTRUCTURES

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The constructed model of generation of K_α radiation under vacuum heating of electrons by a femtosecond laser pulse near the surface of spherical clusters covering a foil describes the measurements of hot electron temperature and K_α yield at a cluster diameter of less than or of the order of the wavelength [1].

When the flat targets are irradiated by the p-polarized laser pulses with an intensity 2×10^{17} W/cm^2, significant decrease (by 100 times) in the conversion of the laser energy into the energy of K_α emission is observed with decreasing the wavelength from 1.24 to 0.4 μm. It is shown that in the case of short-wavelength laser radiation the efficiency of vacuum heating was limited by the condition that the oscillation amplitude of the hot electrons in the accelerating laser field have to exceed plasma scale length in the vicinity of the critical electron density.

When the laser field is perpendicularly incident on the foil, covered with nanocylinders, the electrons are accelerated by a component of the electric field, normal to the “illuminated” surface of each cylinder. Then they return into the cylinder, get out of its “shadow” surface and fall onto the foil to produce K_α radiation. It is shown that the maximum value of the accelerating field is obtained when the laser field is polarized in the plain formed by the axis of the cylinder and the wave vector. In this case, the influence of the field near the “shadow” surface of the cylinder on the accelerated electrons can be neglected. The maximum yield of K_α radiation is reached with the angle of obliquity of the cylinders and the ratio between their diameter and the wavelength, which correspond to the maximum value of the accelerating field. The geometrical characteristics of the target, in which the x-ray yield increases by more than an order of value compared to using the target covered with closely packed spherical clusters, are determined.

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THERMODYNAMIC, TRANSPORT AND OPTICAL PROPERTIES OF PLASTICS, USED FOR THE CONTRAST IMPROVEMENT OF INTENSE LASER PULSES

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Plastics are widely used in the experiments on the interaction of the intense laser radiation with matter. The research at the PHELIX laser facility at GSI is one of such experiments; plastic films are used here to improve the contrast of laser pulses. The information on the matter properties is necessary for the numerical simulation of these experiments.

This work is devoted to the *ab initio* calculation of thermodynamic, transport and optical properties of plastics. The plastics of the effective composition CH_2 are considered. The density is kept fixed at 0.954 g/cm^3, the temperatures are varied from 5 kK up to 100 kK. The ion temperature equals the electron temperature. The calculation is based on the quantum molecular dynamics (QMD), density functional theory (DFT) and the Kubo-Greenwood formula. The QMD-simulation and the band structure calculation in the framework of DFT are performed using the VASP package [1]. The method and the choice of technical parameters in the similar calculations are described in detail in our previous paper [2].

The temperature dependence of the static electrical conductivity is the most interesting result obtained in this work. At the temperatures from 5 kK up to 20 kK the static electrical conductivity grows rapidly as the temperature grows; conductivity is almost constant for the temperatures from 20 kK up to 60 kK; conductivity slightly grows again for the temperatures from 60 kK up to 100 kK.

The dynamic electrical conductivity has the distinct non-Drude shape at the low temperatures. As well as the static electrical conductivity, the dynamic one does not change at the temperatures from 20 kK up to 60 kK as the temperature grows.

The thermal conductivity increases as the temperature grows in the whole range from 5 kK up to 100 kK. The thermoelectric term gives very significant contribution to the thermal conductivity for the temperatures $T \geq 50$ kK.

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THEORETICAL AND EXPERIMENTAL STUDIES OF RADIATIVE AND GAS DYNAMIC PROPERTIES OF SUBSTANCES AT HIGH ENERGY DENSITY IN MATTER

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Mathematical modelling of radiative and gas-dynamic processes in substances at high energy density is carried out for experiments, where both laser and heavy ion beams are used. Important features of the theoretical model, known as the ion model (IM), which is used for quantum mechanical calculations of radiative opacity, are discussed. Reliability of (IM) results is tested with experiment, where measurements of X-pinch radiation energy yield for two exploding wire materials, NiCr and Alloy 188 were made. Theoretical estimations of radiative efficiency are compared with experimental results, and (IM) calculations agree well with the experimental data [1]. Subsequently, the theoretical approach was used for temperature diagnostics of CHO plasma target in combined laser–heavy ion beam experiments [2]. Joint radiative and gas-dynamic calculations are performed for comparison with experiment, where hohlraum radiation transmits through the CHO plasma target, and the share of absorbed radiation energy is compared with experiment [3]. Study of radiative properties of CHO plasma with little admixture of gold is carried out as well. Specific dependence of the Rosseland mean on plasma temperature is discussed for gold plasma.

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AGREED MATHEMATICAL AND LABORATORY MODELING OF MATTER AND ENERGY TRANSPORT IN HETEROGENEOUS MEDIA

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Modern stands allow create for a short time extreme states of matter at high density and temperature. At this precise measurements show that for localized and symmetrized conditions of energy intensive flows are formed in the whole medium including the plane of symmetry. Spatially ordered or irregular pattern to the individual components separated by sharp interfaces are observed in systems of all scaled, from intergalactic of millions of light years to micron in laboratory flows (examples are given). Theory of the formation of the flow structure has not yet been developed.

As the basis for a coherent mathematical and laboratory modeling of a flow in a wide range of parameters fundamental system, including the equation of state, continuity, transfer of energy and matter, supplemented by physically reasonable initial and boundary conditions was used [1]. Independent sources of energy and matter with different spatio-temporal parameters are added in the set. Conducted analysis by group-theoretical methods has shown compliance of the set with the fundamental principles of physics, unlike many approximate and constitutive models [2].

The equations are analyzed taking into account the compatibility condition determining the rank of the complete system, the exponent of the linearized part, the degree of the characteristic (dispersion) equation. Given intrinsic spatio-temporal and energetic scales of the se determine the condition of the experiment completeness and the requirements for metrology [1]. Classification of infinitesimal flow components by the singular perturbation theory is provided. Calculations show that the regular solutions characterize the energetics and dynamics of flow, and singularly perturbed solutions, defining by dissipative coefficients prescribe the geometry of domains with a high concentration of markers and increased energy dissipation rate [3].

Physical modeling conducted for the two groups of flows: stratified, characterizing the processes in the environment, and rapidly formed flow at impact of the falling drops on a liquid. In the latter case a relatively slowly falling droplets form a thin fast jets inside the targeted fluid [4], streamers in the air and generate acoustic pulses with a frequency above 100 kHz [5].

Visualization shows a satisfactory agreement between the results of mathematical and laboratory modeling of diffusion induced flows on the topography [6], propagation [7] and the generation of periodic internal wave beams by compact sources [8, 9], the direct generation of fine-flow components in the wave zone [10]. Calculations agree with the data independently performed experiments with an error of a few percent [11, 12]. The universality of mechanisms of marker filaments formation in initially homogeneous fields in wave and eddy flows is shown [13, 14].

On the example of underwater acoustics and dynamics processes initiated by the impact of a drop on the liquid surface, the influence of atomic and molecular interactions on the macroscopic hydrodynamics and acoustics of unsteady flows is discussed [4, 5]. Spatio-temporal invariance of the fundamental system of equations allows us to construct consistent model of flows in a wide range of governing parameters and justifies the extrapolation of the results of modeling studies on the most extreme states of matter.

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STUDY THE DYNAMIC TENSILE STRENGTH OF GRAPHITE IN STRESS PRODUCED BY NANOSECOND AND PICOSECOND LASER ACTIONS

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On laser systems "Kamerton-T" (GPI, Moscow, Russia) and PHELIX (GSI, Darmstadt, Germany) it was studied experimentally spallation phenomena in a graphite target with nanosecond and picosecond shock-wave action. In a range of strain rates from 10^6 to 10^7 1/s on the first time data of dynamic mechanical strength of this material were obtained. Spalling was observed not only on the back side of the target, but also on its front surface. By using optical and scanning electron microscopy, the morphology of the front and back surfaces of the targets studied. A comparison of the dynamic strength of graphite with the dynamic strength of synthetic diamond for which data were obtained from studies of 2013 was done.

USING LiF CRYSTALS FOR 3D VISUALIZATION OF SACLA XFEL BEAM FOCUSING PROPERTIES

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Measurement of energy distribution of XFEL beam in the caustic of focusing system is very important both for correct evaluation of X-ray fluence in the different cross-sections of such beams and for future improving the Kirkpatrick based focusing systems, which are now typically applied for such purposes. Different methods use to exam the XFEL beam parameters. For example, a grating interferometer, utilizing the Talbot effect, which enables to obtain wave front profiles of SACLA XFEL beam and measures the focal spot size with extremely small size, was developed. Another sophisticated approach for measurements of focal spot size is based on knife-edge scan method. All above mentioned methods have a very high spatial resolution in the scale of tens nm, but could not provide single shot information about spot size distribution of focused XFEL beam along the focusing caustic and, particular, along of XFEL beam propagation after meeting a surface of the target. At the same time such information is crucial for correct evaluation of parameters in many investigations such as: a formation of new type of matter; a surface nanomodification and an ablation of solid materials under hard X-ray irradiation; investigations in the field of high energy density science.

We propose another approach for characterization of focusing caustic of XFEL beam inside bulk material: a direct XFEL beam irradiation of a LiF crystal, which is very promising candidate as a submicron resolution hard X-ray detector.LiF crystal X-ray detectors were previously successfully used for 2D characterization of focusing properties of EUV radiation of transient -collisional soft X-ray lasers and a SASE-FEL beam. It is well known that LiF, as other alkali halide crystals, can host different types of stable color centers (CCs), produced under bombardment by ionizing radiation, like high energy photons and elementary particles, gamma and hard x-rays, neutrons, electrons, and ions. Under optical excitation by properly selected pumping UV light, several types of CCs in LiF emit light in the visible spectral range even at room temperature. Since the dimension of the single CC is less than one nm, and the CCs concentration can reach very high values, three-dimensional images with high spatial resolution (much smaller than 1 micron) can be generated by ionizing radiation in LiF material. At the same time final spatial resolution of obtained images will depend from spatial resolution of readout system and could reach 50 nm in the case of using scanning near field luminescence microscope or about 200 nm, when confocal luminescence microscope is applied.

Here we show, that by means of the LiF crystal detector, a 3D characterization of 10 keV photon energy SACLA XFEL beam focusing inside the solid materials is possible with around 1 micron spatial resolution. Due to high dynamic range of LiF crystal X-ray detector aberration properties of Kirkpatrick based focusing systems could be investigated. High sensitivity of the LiF crystal detector allows measurements of intensity distribution at focusing spot far from the best focus position. Proposed method could be used for characterization and optimization of different focusing systems developed at XFEL and synchrotron facilities.

EXPERIMENTAL INVESTIGATION OF MATERIAL PROPERTIES IN SHOCK WAVES LOADING BY LIGHT GAS GUN

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Materials with anomalous compressibility under shock loading conditions (cerium, docosane, porous medium) can be used as targets. They are a very interesting subject for proton radiography studies due to the anomalous structure of the resulting compression waves and the unusually high jumps of density observed during their phase transitions. Abnormal compressibility may occur due to thermodynamic properties (cerium) and/or irreversible deformation dynamics (the porous medium). Theoretical models for describing the anomalous compressibility and behavior of different materials under extreme conditions are still not developed.

As target materials one can use heterogeneous media with a strong anisotropy of physical properties (e.g. carbon composites, fiberglass, organo-plastics). Shock wave compression of carbon plastics generates a two-wave configuration associated with different propagation velocities along the reinforcing fibers and the polymer matrix. The range of the existence of the two-wave configuration depending on the wave parameters and the stress amplitude should be determined. This is needed for the development of models which adequately describe the behavior of mater ial s under conditions of extreme compression. For this one has to measure the density of the sample under shock loading conditions which can be uniquely done by proton radiography.

If a target is made of inert or chemically active liquid, one can study their spall strength. This phenomenon is of great scientific interest because it allows to obtain negative pressures in liquids and to reach regions of the phase diagram which cannot be achieved by other methods. The kinetics of homogeneous nucleation leading to pore formation, the subsequent growth of which results in spalling, has not been studied in detail, although it is widely used to interpret the data on pulse destruction of liquids. The proton radiography method will allow to directly observe the dynamics of pore formation, which shows up as a change of the liquid density in the fracture zone.

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