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The book consists of the abstracts of plenary, oral and poster contributions to the conference.name (March 1–6, 2026, Elbrus, Russia). The presentations deal with the contemporary investigations in the field of physics of extreme states of matter. The conference topics are as follows: equations of state and constitutive equations for matter under extreme conditions at high pressures and temperatures; shock waves, detonation and combustion physics; interaction of intense laser, x-ray and microwave radiation, powerful particle beams with matter; experimental techniques of generation and diagnostics of extreme states of matter; methods of mathematical modeling in physics of extreme states of matter; high-energy astrophysics; physics of low-temperature and non-ideal plasma; physical issues of power engineering and technology aspects.

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1. Equations of State for Matter

From strongly coupled dusty plasma to active Brownian motors: State of the art and future prospects

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When laser radiation effects on charged (Coulomb) Brownian particles of micron size levitating in plasma, viscous liquid or superfluid helium, complex particle motion can be observed if they absorb radiation energy. Such particles can be considered as active Brownian motors, the movement of which is controlled by radiation. The changes in entropy and entropy fluxes in systems of active Brownian motors in a high-frequency discharge plasma were experimentally studied when exposed to laser radiation of varying intensity, under conditions when the number of particles in the structure depended on the effect of laser radiation.

An experimental study of the energy storage mechanism has been carried out for a drop of an emulsion of complex composition (active Brownian motor) containing absorbing inclusions (active Brownian particles) inside.

The effect of intra-droplet motion of light-absorbing particles upon changes in entropy and entropy fluxes for an active Brownian motor (drops of an emulsion of complex composition) during its movement under the influence of laser radiation of varying intensity has been experimentally studied. Estimates of the entropy outflow for different laser radiation intensities are carried out.

The formation and dynamics of active Brownian motors in superfluid helium levitating in an inhomogeneous magnetic field under the influence of laser radiation of varying intensity has been experimentally studied.

The work was supported by the Russian Science Foundation (grant No. 25-12-00406).

In search for sources of energy and matter

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In this talk, an overview of research and projects within the scientific program of the National Center for Physics and Mathematics aimed at gaining new knowledge on the structure of nuclear matter, the properties of the quantum vacuum and the nature of dark matter is provided. Particular attention is paid to the problems of nuclear photonics, nonlinear quantum electrodynamics of vacuum and electron-positron plasma, as well as to the search for signals of low-energy neutrinos and axion-like particles. The concepts, design and status of work on the creation of large research facilities IICS, XCELS, SATURNE and CASH are discussed.

Physics of extreme states of matter in the works of V. E. Fortov and his school

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The works in the field of physics of extreme states of matter by academician V. E. Fortov and his scientific school in Chernogolovka at the Federal Research Center for Problems of Chemical Physics and Medicinal Chemistry of the Russian Academy of Sciences (formerly the Institute of Problems of Chemical Physics of the Russian Academy of Sciences) are considered from a historical perspective. The results of the 1970s, which laid the foundation for the direction of dynamic methods for studying non-ideal plasma, are presented. The development and current state of the problem of thermodynamic and transport properties of gaseous media is discussed. The results of measurements of the properties of condensed materials under compression by powerful shock waves are presented in a fundamental way. The results of calculations based on modern models of equations of state are presented. The issues of numerical modeling of processes under extreme conditions and databases on material properties are considered.

Study of the equations of state for materials under extreme conditions at high pressures and temperatures: Outlook

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The equation of state for matter is necessary to solve various problems of high energy density physics using methods of continuum mechanics. The reliability of knowledge of the equation of state determines the correspondence between the results of numerical modeling and the available experimental information about the processes being modeled. Thereupon, the study of the thermodynamic properties of various materials under extreme conditions is of interest both for obtaining fundamental knowledge and for solving applied problems.

In the present communication, a brief overview of promising methods for experimental study and theoretical description of the thermodynamics of various materials at high pressures and temperatures is provided. Some results of measuring the parameters of shock-compression and isentropic-expansion waves in condensed media at high energy densities are considered. Examples of equation-of-state models based on different thermodynamic potentials and the results of calculations using these models are also given in comparison with available experimental data for some elements (aluminum, iron, molybdenum) and compounds (silicon dioxide, polystyrene). Finally, conclusions are drawn about the outlook for further research into the thermodynamics of extreme states of matter at high pressures and temperatures.

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Theoretical modeling of thermophysical and X-ray spectral properties of dense ionized matter

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To appropriately simulate the processes and effects occurring at high energy densities, one needs to develop a handful of theoretical methods to calculate high-accuracy atomic data and x-ray emission spectra of multielectron ions in hot plasmas, provide realistic representation of dense ionized matter over a wide range of temperatures and densities along with the consistent description of its thermophysical properties (thermodynamical, optical, dielectric, transport, and structural) and fast-ion energy losses. RFNC-VNIITF efforts in this direction are based on the use of the well-mastered up-to-date models to generate the necessary data on atomic structure and atomic processes, chemical-picture-based model of nonideal plasmas, average atom models providing various methods to include ion-ion correlations, pseudoatom molecular dynamics modeling, average-atom collisional-radiative model of non-LTE plasmas, and a new version of the line-shape model for multielectron ions allowing for the main line-broadening mechanisms in plasmas.

We present a review of theoretical work performed at RFNC-VNIITF in the direction discussed and provide a number of comparisons of the modelled thermophysical and x-ray spectral properties the experimental and other theoretical data.

Approximation of correction functions in the refined Thomas–Fermi model

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The thermodynamics of substance electrons in the concept of spherical Wigner-Seitz cells in the semi-classical approximation is presented as an expansion in the semi-classical parameter ξ within the framework of the self-consistent field model. The zero approximation by ξ corresponds to the Thomas-Fermi (TF) model, and the following terms are the exchange, quantum (gradient) and shell corrections. Smallness condition ξ is violated near the nucleus under any external conditions. The consequences of this are: 1. overestimated values of integral energy quantities in the TF model; 2. divergence at zero of volume integrals for gradient corrections to these energy quantities; 3. in the regions of ultrahigh compressions or temperatures, the results of the perturbation theory valid there are not reproduced. To eliminate the defects, modifications of the expressions for the gradient correction to free energy of electrons and for the shell correction to number of their states have been proposed [1]. The modification includes the introduction of the rather complex functions $\phi(x)$ and $\Psi_k(y)$, which require additional computational efforts. In this paper, their approximations are proposed: $\phi(x) = \frac{2}{45}x^3e^{-x} + (1 - e^{-x})[\frac{x}{3} - \frac{1}{2}\text{arctg}\frac{2x}{3}]$, $\Psi_k(y) = \Psi(y) = \text{tg}[\frac{\pi}{8} - \frac{1}{2}\text{arctg}(\text{th}(\frac{\pi y}{4}))]$.

[1] Shpatakovskaya G V 2012 *Physics-USpekhi* **55** 429–464

The thermodynamically consistent model of ionic and electronic subsystems within the average-atom framework

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In the routine approach to constructing a complete thermodynamic model of an electron–ion system within the average-atom framework, the electronic subsystem is described using thermodynamically consistent quantum-statistical models, while the ionic subsystem is typically treated within simpler approximations [1]. It is commonly assumed that the ionic contribution to the total thermodynamic functions is small compared to the electronic one, and therefore possible thermodynamic inconsistency in the ionic part does not significantly affect the final equation of state.

However, investigations of these models in parameter regimes characteristic of shock-compression experiments demonstrate that the ionic contribution can become comparable to the electronic one [2].

In the present work, an approach to constructing a thermodynamically consistent model of the ionic subsystem within the average-atom framework based upon the one-component plasma approximation [3] is investigated. An explicit expression is used for the ionic free energy as a function of the effective ion charge obtained from the Thomas–Fermi model, or the Thomas–Fermi model with corrections, or the Hartree–Fock–Slater model [1] for electronic subsystem.

This work is financially supported by the Russian Science Foundation (grant No.25-19-00944, <https://rscf.ru/project/25-19-00944/>).

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Equation of state for the liquid phase of scandium based upon a simple thermodynamic model

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The solution of many problems in modern science is associated with the need to conduct hydrodynamic modeling of physical processes in matter, which requires knowledge of the properties of the system under consideration. Information about the thermodynamic characteristics of a material is usually specified in the form of an equation of state, which acts as a closure relation for a system of equations expressing the laws of conservation of mass, energy, and momentum.

Scandium stands out among the substances used to solve applied problems in physics and power engineering. It is necessary to know the properties of this rare earth metal over a wide range of pressures and temperatures. In this work, an equation of state for scandium in the liquid phase is proposed based on a simple semiempirical model. Functional dependences of specific free energy on specific volume and absolute temperature are used. The parameters of the model dependences were determined based upon the condition of best describing the experimental data. Using the resulting equation of state, the characteristics of scandium under shock loading and thermal expansion were calculated. Agreement between the calculated results and experimental data is achieved.

The equation of state for the liquid phase of scandium proposed in this work can be successfully integrated into software packages for mathematical modeling of physical processes at high pressures and temperatures.

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Equation of state for aluminum oxide and mixtures on its basis at high pressures and temperatures in shock waves

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In this work, equations of state for aluminum oxide (alumina) and a number of substances included in mixtures with it are constructed on the basis of a thermodynamic model [1], which makes it possible to describe data from shock compression experiments over a wide range of pressures and temperatures. The equations of state for alumina-based mixtures are constructed under the assumption of establishing thermal and mechanical equilibrium between the components [1]. The calculated shock (Hugoniot) adiabats for mixtures based upon aluminum oxide as well as for their components are compared with experimental data over the entire studied range of densities and pressures. The obtained good agreement between the adiabats and the data confirms the reliability of the presented equations of state, which makes them suitable for numerical modeling of dynamic processes at high pressures and temperatures.

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[1] Seredkin N N and Khishchenko K V 2024 *High Temp.* **62** 450–453

Thermodynamic properties of nickel in a wide range of specific volumes and specific internal energies under shock compression of solid and porous samples

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Some equation-of-state models used to describe the thermodynamic properties of a material in the region of high energy densities are considered in this work. These models differ in the form of the dependence of the Grüneisen coefficient on the specific volume and specific internal energy. Within the framework of these models, equations of state were constructed for the transition metal nickel, and calculations of thermodynamic characteristics were carried out in a wide range of changes in volumes and internal energies (for a unit mass of the substance), which is accessible for study in shock-wave experiments. Based upon a comparison of the results of calculations of shock adiabats for nickel samples of different initial densities with the available experimental data, the boundaries of the applicability region of each model are established. The constructed equations of state for nickel can be used to solve problems of hydrodynamic modeling of processes in this metal under high dynamic pressures. This work is financially supported by the Russian Science Foundation (grant No.25-19-00944, <https://rscf.ru/project/25-19-00944/>).

Ab initio investigation of liquid sodium thermodynamics in near-critical states

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Liquid metals such as sodium are attractive coolants in the nuclear power industry because their high thermal conductivity and flowability enable efficient heat removal and high heat-transfer rates in power systems. Since sodium is widely used in fast reactors, reliable design and safety analysis of sodium-cooled systems requires accurate thermophysical properties of sodium over broad liquid and near-critical conditions where experiments are limited.

The quantum molecular dynamics (QMD) method is increasingly used to predict the physical properties of materials in temperature ranges where it is difficult to reproduce experimental data or where experiments are completely impractical. The approach combines finite-temperature density functional theory for electrons with classical dynamics of ions and does not depend on any additional empirical data.

The aim of this work is to investigate the thermodynamic and transport properties of sodium in the liquid and near-critical conditions using QMD. We performed simulations on a detailed grid of isotherms and isochores in the liquid phase and in the vicinity of the two-phase boundary. Based on the obtained equation of state, we estimated the critical-point parameters, transport coefficients, including viscosity and thermal conductivity, and derived thermal expansion behaviour. The available relevant experimental data are also analysed and discussed.

The research was supported by the Russian Science Foundation (grant No. 24-79-00136, <https://rscf.ru/project/24-79-00136/>).

Ab initio extracting of separate electronic contributions to transition metals' transport properties

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The s - d scattering mechanism, first proposed by Mott [1], is the dominant source of electrical resistivity in transition metals, primarily driven by electron–phonon interactions. Accurate modeling of s - d electronic transitions is essential for understanding processes under ultrafast laser pulses in thin metallic films. Allen's approach to transport properties calculations [2] applies broadly across metals and successfully reproduces the unusual nonlinear temperature dependence of resistivity in several transition metals. It has been suggested [3] that the ρ_{ss} contribution—where both initial and final scattering states are s -like—in Pd can be approximated by the resistivity of Ag—the nearest non-transition-metal neighbor of Pd. In this work, we consider several criteria for distinguishing Bloch states of s - and d -type to more accurately select strongly hybridized states close to the chemical potential. We compute separate electronic contributions to total resistivity of Pd using Allen's method built upon *ab initio* calculations and Wannier interpolation as implemented in our SKiES code [2]. The results presented for both electrical resistivity and phonon linewidth in Pd. The work was supported by the Russian Science Foundation (Grant No. 24-79-00136).

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First-principles calculation of resistivity for neon at high pressure and high temperature

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We investigate the electrical conductivity of neon under various thermodynamic conditions using the Kubo–Greenwood formula (KGF), which helps us to understand the process of neon metallization at high pressures.

A new mathematically rigorous criterion for selecting the optimal broadening parameter of the finite-width δ -function approximation in KGF is presented. The proposed criterion is based on an analysis of the stability of the dynamic conductivity curve and minimizing the root mean square deviation between curves obtained by sequentially varying the broadening parameter value.

This approach is applied to calculate the electrical conductivity for neon in the ranges of temperature up to 100 kK and density up to 14 g/cm³. It is shown that the choice of broadening parameter significantly affects the accuracy of the static conductivity calculation. The approach provides the reproducibility and physical stability of the results and can be applied to a wide range of problems requiring the calculation of transport and optical properties of materials.

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Influence of exposure duration on impulse material fracture

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Analysis of the process of impulse destruction revealed a determining effect on its development of the potential energy stored in the material. Existence Time of stress state is introduced as material parameter characterizing process temporality and material response to pulse action. The general dependence of destructive loads on the duration of the impact in the brittle fracture mode characteristic of high-speed loading was revealed. Transition to brittle mode of destruction of highly plastic polymer films at high-speed loading by magnetic pulse method of creation of controlled pressure pulses, confirming results of analytical evaluations, is experimentally demonstrated. The individuality of the behavior of materials is determined by their static strength and Existence Time of stress state.

The work was supported by State Atomic Energy Corporation Rosatom and Ministry of Science and Higher Education of Russian Federation under Federal Project 3 (FP3), project # FSEG-2025-0005 “Development of design and technological solutions to ensure mechanical strength and cooling of the central solenoid of tokamak TRT”

Dynamic stability and simulation of the laser shock peening of titanium samples obtained by laser additive technology and welding

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The paper presents the results of theoretical and experimental studies of the laser shock peening (LSP) process of additive grown and welded samples, made from titanium alloy. A theoretical model of the dynamic stability of the process has been developed, taking into account the multi-factorial impact of the modes and conditions of laser induced hardening on the characteristics and properties of the samples. A mathematical model of the loss of stability phenomena has been presented for titanium sample based on the theory of bifurcations, which describes the transition from a stable wave process to an unstable one through pitchfork bifurcation caused by the non-linear interaction of a shock wave with the substrate material. The critical laser flux density corresponding to the optimal value of the pulsed pressure of the plasma torch on the sample surface has been calculated. Numerical modeling of 3D printing and welding of samples was performed as well. The optimization was performed using the Hopfield neural network model. On the treated surface and in underlaying material the micro-hardness, strengthening degree, roughness, residual stresses, and samples deflection were experimentally determined. Digital image correlation was performed using the OpenCV Python library. The obtained results were used to validate the evolutionary mathematical model of the LSP process.

Estimation of hadronic matter viscosity from atomic nuclei spectroscopy and neutron stars observation data

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Liquid drop model of nuclei capillary oscillations with account of viscosity have been developed in our previous paper [1]. Comparison of even spherical nuclei's quadrupole and octupole vibration frequencies give that nuclei matter viscosity η falls in the interval $4.2 - 7.6 \text{ MeV fm}^{-2} \text{ c}^{-1}$. These results we applied to neutron stars gravitational quadrupole oscillations that take place right after their formation in collapse processes. Attenuation decrement for neutron star with mass M can be expressed in the form

$$\gamma = \frac{1}{3} \frac{\hbar^3}{E_p^2} \frac{\eta a}{r_g}, \quad (1)$$

were $r_g = \frac{2GM}{c^2}$, $E_p = 1.22 \cdot 10^{19} \text{ GeV}$, $\eta = 4.5 \text{ MeV fm}^{-2} \text{ c}^{-1}$. For neutron core mass equal solar mass one can find that $\gamma = 6.8 \cdot 10^{-17} \text{ s}^{-1}$ and corresponding attenuation is equal to $\tau = 4.8 \cdot 10^8 \text{ years}$. Comparison of these results with RHIC data gives the following expression quark-gluon plasma viscosity

$$\eta = 1.5 \times 10^{-2} T \text{ MeV fm}^{-2} \text{ c}^{-1}, \quad (2)$$

where T is the temperature of quark-gluon plasma in MeV .

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Study of compressibility of materials used in three-dimensional printing using synchrotron radiation

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In this work, the results of a study of the shock wave compressibility of acrylonitrile butadiene styrene (ABS), fluoroplastic and photopolymer resin from Formalabs “ClearResin” are presented. Compression of samples was carried out using a charge of plastic explosive. The process of compression was recorded using radiography by synchrotron radiation. The study was conducted for purposes of validation of equations of state for materials used in three-dimensional printing.

Cavitation collapse of bubbles filled with gas of hydrogen isotopes in water

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Until now, the question of the attainability of conditions for the implementation of fusion reactions of light nuclei during ultrasonic or laser cavitation remains unclear [1]. The low-background conditions of the Baksan Neutrino Observatory make it possible to measure ultra-low neutron fluxes in the $d + d \rightarrow 3He + n$ reaction, as well as the residual activity of tritium synthesized in the $d + d \rightarrow t + p$ channel. Tritium will decay according to the $3H \rightarrow 3He + \bar{\nu}$ scheme with a period of 12.32 years, which makes it possible to register single acts of beta decay on low-background installations. An experimental setup for ultrasonic and laser generation of bubbles in deuterated liquids with the ability to measure light, sound and neutron yields is presented. Preliminary experimental results on the dynamics of the collapse of bubbles filled with argon in distilled water are analyzed. The interpretation of the experiment was carried out within the framework of the generalized Rayleigh-Plesset model [2].

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Shock wave properties of polymethylmethacrylate: Shock compressibility and temperature

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Understanding the shock-wave response of polymethylmethacrylate (PMMA) is important, as this material is used in various explosive devices. In particular, two-staged devices for explosive launching of plates (sloika), and Mach conical and cylindrical cumulative shock wave generators can be noticed. The principal shock adiabat of PMMA has been well studied in the range of pressures up to 100 GPa, but there are only a few data points at higher pressures, obtained under conditions of an underground nuclear explosion (120, 200 and 500 GPa). Recently, Z-machine produced pressures up to 650 GPa in PMMA. This work provides an overview of experiments with Mach cumulative generators, where it was possible to determine the shock compressibility and temperature of shock wave front in PMMA. In the first type of experiments, the shock adiabat was determined by impedance matching with Quartz etalonne, while the temperature of the shock front was measured by fast optical pyrometry. In the second type of experiments, only the temperature and velocity of the shock front were measured, and the pressure was calculated using both our and existed dataset on Hugoniot of PMMA. The maximum obtained pressure in PMMA was up to 700 GPa. The temperatures of shock wave at such pressures have been obtained for the first time.

Power potentials for constructing polymorphic equations of state of polycrystals

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Within the framework of power potentials, two approaches to the construction of equations of state of polycrystalline substances were considered. These approaches were implemented using the polymorphic phases and melt of silicon dioxide (SiO_2) as an example. As a result, the low-parameter polymorphic equations of state were built for it.

Experiments on shock compression of monocrystalline samples of SiO_2 were carried out using explosive cumulative generators [1]. The shock compressibility of the samples was determined by impedance matching with aluminum standard, wave velocities were measured using a time-of-travel optical technique. The brightness temperature of shock front was recorded by a high-speed optical pyrometer.

The adequacy of the constructed equations of state was checked by comparing the results of calculations taking into account polymorphic transitions and melting, with the experimental data on the phase diagram and shock Hugoniot of silicon dioxide. It has been found that the Murnaghan equation approach is more preferable for constructing of phase diagrams in the region of moderate pressures. However, in the region of high pressures, the approach to constructing equations of state in the form of Mi – Gruneisen allows us to obtain a good correspondence between the calculated and experimental data on shock adiabat.

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Comparative analysis of enhanced sampling and direct molecular dynamics for binding free energies

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The precise determination of thermodynamic equilibrium constants for dissolved diatomic molecules is investigated using a model interatomic potential. We establish a rigorous comparison between unbiased “brute-force” molecular dynamics (quantities are obtained directly by simulating sufficiently large molecular systems) and enhanced sampling techniques, specifically Metadynamics [1] and Umbrella Integration [2]. A consistent thermodynamic framework is applied to convert the potential of mean force into standard binding free energies, incorporating necessary entropic corrections for radial collective variables. The study focuses on the accuracy and convergence of these methods across a range of temperatures. We observe excellent quantitative agreement between the biased and unbiased approaches, with relative errors in the determination of the equilibrium constant being equal $1\% \pm 0.3\%$. This was achieved by performing sufficiently lengthy calculations and by systematically analyzing sources of uncertainty, including thermostat artifacts and the definition of the bound state. Thus we validate a robust pipeline for predicting chemical equilibrium in complex solvents with high precision.

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Speckl dynamics method to study melting line of nickel monoaluminide

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We present a newly developed method for studying melting processes. Lasers produce stable speckle interference patterns on a surface. Phase transitions, such as melting, change it. The experimental setup combines a speckle-patterns visualization system with a multispectral camera and double acousto-optic imaging spectrometer. It allows simultaneous control of speckle-patterns dynamics [1] and temperature distribution in laser heating diamond anvil cell [2]. Such approach allowed to determine nickel monoaluminide (NiAl) melting line experimentally for the first time [2]. We show that the experimental points are slightly lower than those calculated using molecular dynamics by the one-phase and two-phase approaches. This research was performed with the financial support of the Ministry of Science and Higher Education of the Russian Federation (FFNS-2022-0008) The research was carried out using the unique scientific installation ‘Laser Heating in DAC’ in STC UI RAS [ID: 507563, <https://unu.ntcup.ru>].

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Quantum chemical computations of argon carbides in the gas phase

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The demand for accurate data regarding the energy structure of argon carbides is primarily driven by the applications of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and thermodynamic modeling involving argon-containing ions to resolve the equilibrium state of complex mixtures. Furthermore, such data are essential for subsequent studies aimed at determining the thermodynamic and transport properties of argon-carbon plasmas [1]. These results may also be relevant for specific problems utilizing the low reactivity of argon to model fluid flow through carbon-based structures [2].

This study presents quantum-chemical calculations for the ArC^+ molecule, along with a comparison of the calculated potential energy curves (PECs) with experimental data reported in [3]. The simulations were performed using the ORCA software package [4] employing the multireference configuration interaction (MRCI) method. Results were obtained for several basis sets, followed by extrapolation to the complete basis set (CBS) limit.

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Method for calculating the properties of pure substances using critical point theory

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Within the framework of the phenomenological theory of the critical point [1], an equation of state for pure substances in the form of the Helmholtz free energy, F , is proposed. In this case, the Helmholtz free energy structurally includes three components: the first component reflects the behavior of the substance in the regular part of the thermodynamic surface; the second is responsible for the fulfillment of the power laws of the scaling theory in the vicinity of the critical point, which tends to zero in the region of a rarefied gas and is equal to unity at the critical point; the third component is the ideal-gas component of the Helmholtz free energy. All parameters of the singular component are determined using only critical indices and generalized dependencies for the critical amplitudes of the isochoric heat capacity and the saturation line [2, 3]. Thus, when determining the parameters of the singular component of the proposed equation of state, there is no need to use experimental information on the substances properties. Thus, the proposed approach can be used to develop equations of state for technically important substances whose thermodynamic properties are poorly understood near the critical point.

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GasThermo—web application for computations thermodynamic properties of diatomic ideal gases

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Databases on the thermodynamic properties of substances play an essential role in solving engineering problems, which require thermodynamic modeling. To maintain the relevance of thermodynamic databases, the information in them must be regularly updated and supplemented. This requires the development of modern software that include new ab initio methods that allow for obtaining results for substances that are difficult to study experimentally.

This work aims to solve two main problems by developing a new web application GasThermo. The first is to provide modern software solutions for updating thermodynamic databases and in particular the information system IVTANTHERMO [1]. And the second is to develop tools to estimate the errors introduced by background ions in inductively coupled plasma mass spectrometry (ICP-MS) [2].

GasThermo is a set of web applications, which provide tools for calculation thermodynamic functions of diatomic ideal gases based on traditional molecular constants or potential energy curves of interatomic interactions (which can be obtained using ab initio quantum chemical computations). Also GasThermo has models aimed at assessing the impact of background ions on ICP-MS by thermodynamic modeling. The data for thermodynamic modeling will be taken from the application itself and also from IVTANTHERMO.

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Heuristic methods for verification of thermodynamic function calculations

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The URS-OF (common fund equations of state) software package is developed and maintained at the Russian Federal Nuclear Center—All-Russian Scientific Research Institute of Experimental Physics (RFNC-VNIIEF). The URS-OF program library for calculating substance properties is used by the majority of mathematical physics simulation codes developed at the RFNC-VNIIEF.

Verification of the computational modules in the URS-OF library is a mandatory stage of their development and modernization. Testing on regular parameter grids is computationally expensive under high-dimensional conditions. In this work, a random search method is employed precisely to address the tasks of verifying thermodynamic functions within the URS-OF package.

Tests were implemented that automatically generate random points across wide ranges of densities and temperatures and verify the correctness of calculations in four key directions: verification of the physical correctness of the substance equation of state using the Bethe–Weil conditions and thermodynamic consistency; verification of the consistency of calculation results obtained using different input variables; efficiency analysis of the method using the example of the temperature determination task from a given internal energy; verification of the correctness of thermodynamic function derivative calculations. The proposed set of methods based on random search significantly complements the existing testing system, enhancing its sensitivity to hidden errors and contributing to ensuring high reliability and predictability of calculations in complex physical and technical problems solved at the RFNC-VNIIEF.

Towards temperature-dependent DeePMD potential for hydrogen plasma

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Path-integral Monte Carlo and other quantum simulation methods provide accurate descriptions of hydrogen plasma but are computationally prohibitive for large-scale or long-time molecular dynamics (MD). In contrast, classical MD is highly efficient yet relies on effective interaction models that often fail to capture essential quantum constraints—most notably the Pauli exclusion principle. Machine learning potentials, such as DeepMD [1], offer a promising route to bridge this gap: by training on high-quality reference data, they can reproduce quantum-level accuracy at MD cost. In this work, we take key steps toward a DeepMD potential for hydrogen plasma, focusing on two critical physical ingredients: (i) explicit temperature dependence inherited from the underlying Kelbg pseudopotential [2,3], and (ii) proper treatment of long-range Coulomb interactions via periodic Ewald summation. We show that omitting the latter leads to systematic errors, while its inclusion ensures physical consistency and stability. Training on data in the range $T = 24\text{--}97$ kK ($\Gamma = 0.1\text{--}0.5$) yields excellent accuracy: $R^2 = 0.967$ for energy and $R^2 = 0.987$ for forces, confirming the viability of machine-learned potentials for efficient, large-scale simulations of hydrogen plasma. The research was supported by RSF (grant No. 24-79-00136).

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Scaling models for describing the thermodynamic properties of liquid and gaseous carbon dioxide in the region of liquid–vapor phase equilibrium

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The study of the properties of substances near the region of liquid–vapor phase equilibrium is of interest to modern science, as it allows one to expand theoretical understanding of the thermodynamics of materials undergoing phase transitions. The obtained information about the numerical values of thermodynamic quantities is used to solve applied problems, as well as in mathematical modeling of physical processes near the saturation line.

This work is devoted to the theoretical description of the thermodynamic properties of carbon dioxide in the region of liquid–vapor phase equilibrium. Various scaling models are considered, based on which the temperature and density of liquid and gaseous carbon dioxide on the binodal are calculated. The obtained model dependences are compared with available experimental data. Based on this, a conclusion is made about the possibilities of using the considered models in hydrodynamic modeling of physical processes in carbon dioxide near the region of liquid–vapor phase equilibrium. This work is financially supported by the Russian Science Foundation (grant No.25-19-00944, <https://rscf.ru/project/25-19-00944/>).

Experimental investigation of thermophysical properties of ceramics from equimolar mixture of carbides by microsecond resistive heating method

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The use of microsecond pulsed resistive heating allows one to determine the thermophysical properties of electrically conductive materials at high temperatures, in the premelting region and in the liquid phase. Recently, carbides and carbide ceramics of refractory metals have become increasingly popular, making it important to study their thermophysical properties. These refractory materials are relevant for use in technology and industry, in the construction of nuclear submarines and reactors, in aircraft manufacturing and rocket engineering. Of particular interest is the study of the thermal expansion of these materials at high temperatures and pressures, as experimental data in these areas is insufficient. Our experimental setup implements a microsecond pulsed resistive heating method based on the Joule heating process, which allows us to obtain experimental data above the melting point at a pressure of about 500 bar, in a duration of about 100 μ s. This paper presents the obtained experimental data on the thermal expansion of ceramics from an equimolar mixture of TiC, TaC and NbC carbides at high temperatures. Comparison with literature data in the solid phase showed that the obtained and processed experimental data are reliable.

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Program algorithm for inductive component correction in fast pulse heating experiments

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In experiments with fast pulsed resistive heating to study the thermophysical properties of materials at high temperatures, it is necessary, in particular, to determine the resistive voltage drop at the ends of the sample as accurately as possible. The problem is that since the voltage measurement circuit includes a sample, measuring probes and voltage divider conductors, when a strong heating current flows through the sample, an induced electromotive force is generated. During the experiment, when the current through the sample rapidly changes at the beginning and end of the pulse, a “parasitic” inductive voltage interference occurs in the measurement circuit, which can be observed in the graphs of the measured experimental voltage data. This interference distorts the experimental data and leads to unacceptably large errors during current switching. For these reasons, algorithm and computer program were developed to correct the inductive component of the voltage arising in the measuring circuit. In this work, a unique voltage correction algorithm is presented. The results of the program for correcting the voltage in the measuring circuit are also presented. The developed program allows one to determine the actual value of circuit inductance for each set of experimental data, taking into account the contribution in each experiment. The new algorithm was used to process the obtained data on titanium and niobium carbides at high temperatures and melting point.

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PDV measurements of time intervals

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Nowadays, laser interferometry is widely used to record fast processes. Laser interferometry complexes, currently existing at RFNC-VNIITF and configured as PDV (Photon Doppler Velocimetry) systems, operate at a radiation wavelength of 1550 nm [?] [?]. In some experiments on acquiring data on shock compressibility of materials using PDV system, it is required to determine absolute and relative times of the onset of the phenomenon under study in addition to velocity measurements. The report discusses the possibilities of using PDV systems to measure time intervals for fast processes. Measurement configurations are suggested to level down the complexity of setups and achieve sub nanosecond accuracy in time interval measurements. Error of such measurements are estimated, defined by the complexity of PDV measuring complexes setups and of a system to synchronize the complexes with launching equipment, and by the method of experimental oscillograms processing.

Meta-optimization of the particle swarm method for EOS parametrization

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The wide-range multiphase equations of state (EOS) that describe the thermodynamic properties of matter in rather detail usually have a great number of free parameters whose determination is a difficult problem. Such problems are usually solved with the heuristic optimization methods that may also have their internal parameters. Moreover, these parameters often strongly influence optimization efficiency and depend on many factors such as the particular form of the objective function, the particular implementation of the method, etc. In practice, parametric studies are often taken to determine the coefficients and those giving best results on average are chosen [1]. But such an adjustment of heuristic algorithms may require much more work and time than their implementation and still not virtually ensure their effective performance when the functional is changed. In this paper it is proposed that this shortcoming be removed through a modification of the particle swarm method (PSM) where the inertial, social, and cognitive components are adapted in the course of EOS parametrization. The adaptation is done with another stochastic algorithm, where the sought parameters are weights and the objective function is the rate of PSM convergence. The real genetic algorithm and the particle swarm method were used as meta-optimizers. The paper presents two variants of their use: for the determination of the best PSM parameters prior to EOS parametrization, and for adaptation of PSM parameters directly during the solution of the main problem.

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Non-empirical equation of state for polymethyl methacrylate (PMMA) based on atomistic simulations

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Based on calculations using density functional theory methods, the thermodynamic properties of polymethyl methacrylate were determined in the region of monomer, solid phase, chemical decomposition zone, and warm dense matter state. The considered range of thermodynamic quantities has been significantly expanded compared to previously used atomistic modeling methods by the use of the extended first principles molecular dynamics method.

The calculated equation of state covers the density range of 0.5–6 g/cm³, temperatures of 0–20 MK, and pressures of 0–570 Mbar. This allows directly compare the results of first-principles simulation with calculations using one-center models. The dependence of the calculated shock-wave properties of the investigated system in the low-pressure region on the initial approximation used to represent the original substance was analyzed.

Sodium phase equilibrium line

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A phase equilibrium line (PEL) of sodium has been developed for temperatures from the triple point ($T_t = 371$ K) to the critical point ($T_c = 2503.71$ K). The equations describing the vapor and liquid branches of the saturation line (SL) are consistent with each other both in coefficients and in exponents, and the average diameter of the coexistence curve in a wide vicinity of the critical point satisfies the screening theory. Within the framework of the proposed PEL model, the vapor branch of the SL is described based on the Clapeyron-Clausius equation, which uses not the heat of vaporization, r , but the "apparent" heat of vaporization, $r^* = r/(1 - \rho^-/\rho^+)$, where ρ^- and ρ^+ are the densities of saturated vapor and saturated liquid, respectively. The phase equilibrium line model was tested using the example of describing data on ρ^- , ρ^+ and the saturated vapor pressure of methane, ethane, perfluorooctane, and sulfur hexafluoride [1, 2]. The proposed approach is used to ensure consistency between the thermal and caloric characteristics of sodium in the vicinity of the triple point. Inconsistencies between known data on the heat of vaporization of sodium and the heat capacity of a saturated liquid are revealed. An analysis of the obtained results is presented using the methodology for analyzing the saturation curve of pure substances proposed in [3]. A comparison with known models of the sodium saturation curve is made, in particular, [4].

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Method for calculating the critical amplitude of the saturation line

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The known correlations for the critical amplitude B_0 of the saturation line (SL) take into account only the dependence of $B_0 = B_0(\beta)$ on the acentric factor ω [1], on the critical index of the SL, β , $B_0 = B_0(\omega)$ and on ω and β simultaneously: $B_0 = B_0(\omega, \beta)$ [2]. These correlations have a fundamental drawback: they do not take into account the experimentally established fact of “mixing” of the critical amplitudes B_0 , when a substance with a large acentric factor ω_I has a critical amplitude B_I smaller than the amplitude $B_I I$ of a substance with a smaller acentric factor, $\omega_I I < \omega_I$. The fact of mixing of the B_0 amplitudes can be taken into account if we start from the hypothesis that the critical amplitude of the saturation line is a function of three independent variables: ω , β and the critical compressibility factor, Z_c . The proposed correlation $B_0(\omega, \beta, Z_c) = c_1 + c_2\omega + c_3\beta + c_4Z_c$ was tested on the basis of 36 substances, including UF₆, sodium, cesium and lithium, for which the literature provides data on $B_0 = B_{0,exp}$ at $3.0 \leq \beta \leq 3.85$ and $-0.39 \leq \omega \leq 0.65$. The amplitudes of UF₆, sodium, cesium and lithium were determined on the basis of the saturation line equations [3], respectively. The deviations of the experimental values B_0 from those calculated using the correlation $B_0(\omega, \beta, Z_c)$ for almost all of the substances considered do not exceed 6% in absolute value. The only exceptions are He⁴, sodium and lithium, for which these deviations are somewhat higher.

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Sound velocity measurements in shocked metals such as Ta, Mo, Cu, and Zn

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The result of measurements of longitudinal, C_L , and bulk, C_B , sound velocities are presented for shocked high-purity reference metals such as high-purity tantalum (according to TU 95 234-80), pure molybdenum (according to TU48-19-247-93), copper M1 (according to GOST1535-2016), and zinc Ts0 (according to GOST1180-2021) within the range of pressures 20...380 GPa obtained by the photoelectric method [?, ?]. A brief description of the principle of operation of the method, the setup, and the results of the experiment implementing the rarefaction overtaking technique is provided.

The general dependencies (Berch law) of the sound velocity on density behind the shock front in the solid phase are established, additionally including those in the liquid phase for Zn:

Ta: C_L [km/s] = 0.274ρ [g/cm³] - 0.465 ($11 \leq \sigma_{xx} \leq 272$ GPa).

Mo: C_L [km/s] = 0.521ρ [g/cm³] + 1.494 ($97 \leq \sigma_{xx} \leq 381$ GPa).

Cu: C_L [km/s] = 0.813ρ [g/cm³] - 2.384 ($11 \leq \sigma_{xx} \leq 237$ GPa).

Zn: C_L [km/s] = 0.781ρ [g/cm³] - 1.491 ($49 \leq \sigma_{xx} \leq 93$ GPa).

C_B [km/s] = 1.509ρ [g/cm³] - 10.239 ($133 \leq \sigma_{xx} \leq 187$ GPa).

2. Shock Waves, Detonation and Combustion

Gas-dynamic generation of high-speed plasma jets by cylindrical explosive device

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The RFNC-VNIIEF Institute of Experimental Gas Dynamics and Explosion Physics is conducting work aimed at studying some areas of the controlled thermonuclear fusion. One of these areas is the development of a small-sized thermonuclear neutron source in the form of a cylindrical explosive device with gas-dynamic generation of a high-speed plasma jet of hydrogen isotopes. The first stage in the creation of such a source was the computational and experimental development of a device that allows generating high-speed plasma jets of air. The device is a steel pipe surrounded by a cylindrical explosive charge, inside which there is air. A specially designed cylindrical detonation distributor provides sequential initiation of explosive charge in annular zones located at a given distance from each other with a certain time interval. The scheme and mode of operation of the device are determined by calculation using 2D modeling. Three experiments were carried out with the developed device. In the experiments, the gas flow velocity $U \sim 40\text{--}50$ km/s was recorded, which almost coincided with the predicted design velocity. The experiments have confirmed the possibility of generating the required gas jet velocity parameters in the developed device.

Interaction of a particle flow formed as a result of shock wave ejection with a counter shock wave propagating in gas

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The work presents experimental data on the interaction of a particle flow with a reflected shock wave formed in helium initially at a pressure of $P=2$ atm. The particle flow motion was recorded using laser Doppler interferometry [1]. A model [2] was used for the computational description of particle flow in helium. It was demonstrated that the principles underlying the developed model of particle flow evolution in gaseous medium allow for the correct simulation of all processes occurring with particles (deceleration and fragmentation). A significant change in the size distribution of particles after their interaction with the oncoming shock wave was noted.

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Kinetic model of combustion of coarse-grained gunpowder and its parametric identification

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There are various theoretical approaches to describe the processes that occur during the gunpowder combustion [1]. In recent years, so-called phenomenological models have become widespread. One of these is the model of combustion of coarse-grained gunpowder, the development and description of the positions, as well as the parametrization of which were provided in the present work. Its distinctive feature is taking into account the possibility of both progressive and degressive combustion, which is due to the random distribution of hidden surfaces in the gunpowder.

To determine the parameters of the model, experimental dependences of the pressure of gases on time in a closed explosive bomb for coarse-grained gunpowder of the grade KZDP-2 a loading density of 0.02 to 0.1 g/cm³, obtained at RFNC-VNIIEF, as well as data from [2] for other types of gunpowder, are used.

Numerical modeling of the combustion of powder charges was carried out in a two-dimensional Euler solver, the result of which correctly describe experimental dependencies, which confirms the applicability of the proposed model.

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Shock response of carbon–aramid composite up to 200 GPa

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Due to the prevalent use of composite materials as shields against hypervelocity orbital impacts, research into their shock-wave properties at corresponding pressures is highly relevant. This study investigates the shock compressibility of a carbon-aramid fiber-reinforced polymer. Experiments at pressures up to 200 GPa analyzed the material's response with fibers oriented both longitudinally and transversely to the direction of shock propagation. Particle velocity profiles were recorded using a multichannel laser interferometer. The shock compressibility and the structure of the shock wave front were determined for each orientation. It is shown that shock Hugoniot of composite does not depend on fiber orientation. A distinct kink observed on Hugoniot in shock velocity–particle velocity variables near 25 GPa is attributed to a phase transition in the composite. Furthermore, the results demonstrate that at pressures below 19 GPa, the anisotropic structure of the composite must be considered to correctly describe its shock response. This anisotropy manifests as a two-wave structure in the longitudinal orientation, whereas a single shock wave is observed in the transverse orientation. At higher pressures, it is crucial to consider the phase transition, which alters the shock compressibility of the carbon-aramid composite.

This study was performed in accordance with the program of Ministry of Science and Higher Education of the Russian Federation No.124020600049-8.

Condensation shock wave in supersaturated gas

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For continuous modeling of the volume condensation process in a high-speed metastable gas flow, kinetic models of cluster formation, as well as condensation and evaporation on nanoscale liquid droplets are required. Due to the limitations and inaccuracy of such models, it is sometimes preferable to use the direct molecular dynamics (MD) modeling method to obtain reliable results [1].

In our work, we consider the process of volume condensation of supersaturated pure argon, as well as argon-neon mixture, when they inflow with supersonic speed in a long straight channel of constant cross-section. The atoms are removed at the end of channel, and a steady-state flow regime, in which the spatial profiles of the quantities do not change over time, is gradually established for each initial temperature. Then the simulation data is accumulated and averaged over time, which makes it possible to obtain accurate profiles of the temperature and velocity of two-phase flow, as well as to track the evolution of the cluster size distribution.

It is shown that the gas temperature and pressure increase downstream due to cluster formation, which leads to slow deceleration of the flow. Thus, the local sound speed increases within the flow, and may become less than the local flow speed. This creates a condition for formation of a stationary shock, which sharply slows down and heats the compressed gas.

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Impact response of high-strength ($\alpha + \beta$) titanium alloy Ti–5Al–5Mo–5V over 300–900 K temperature range

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High-strength titanium alloys of the transition class are a promising material for use in heavy-duty structures of aviation, space and military equipment due to their high specific strength and operational reliability. When studying the effects of impact, explosion, and intense pulsed effects on products, it becomes necessary to describe the processes of high strain rate and fracture of titanium alloys during impact compression. This work presents the results of measurements of the Hugoniot elastic limit and spall strength of a titanium alloy of the Ti-5Al-5Mo-5V (VT22) system manufactured by JSC VSMPO-AVISMA Corporation. One-dimensional shock compression pulses were created using an impact plate with velocities from 500 to 1900 m/s. Experimental of the free surface velocity profiles of the samples with a thickness from 0.4 mm to 10 mm were recorded using a VISAR laser interferometer. During the experiments, the maximum compression stress was varied from 4 GPa to 19 GPa. For samples in the hot-rolled state, the influence of temperature in the range from 300 K to 900 K on strength characteristics was evaluated. As a result of the analysis of the data obtained during measurements of the evolution of the elastoplastic shock compression wave, the dependences of the rate of plastic deformation on stress were determined. The values of the spall strength were also evaluated depending on the rate of deformation in the incident load pulse. The work was carried out with the financial support of the RSF project 25-29-00899 (<https://rscf.ru/project/25-29-00899/>).

Model of destruction of metals (lead, tin) in solid and liquid phases under the influence of shock waves of various intensities

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This report presents the results of computational studies of the destruction process of lead and tin in their solid and liquid phases under the influence of strong non-stationary waves. The calculations were performed using a one-dimensional Lagrangian method with a self-consistent system of constitutive relations that takes into account compression, plastic deformation, fracture, and compaction of damaged materials (SCR RING-DRK-L) [?]. The features of the formation of the density distribution of matter are shown.

Software processing of images recorded by the holographic method in shock-wave ejecta experiments

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The shock-wave “dusting” process is the ejection of a stream of particles from a free surface of a material when a shock wave reaches this surface. This particle stream is generated primarily by imperfections in the metal surface finish, which give rise to Richtmyer–Meshkov instability: concave grooves invert and form jets that subsequently break up into numerous fine particles. The most thoroughly studied aspect of this phenomenon is its integral characteristic—the mass-velocity distribution of particles in the ejecta stream—measured using radiography, witness (indicator) plates, and piezoelectric sensors [1]. In the present work, the specifics of the holographic recording setup, a new approach to reconstructing the dust flow at a chosen depth using the angular spectrum method, and algorithms for automating particle detection and characterization are described. These include a neural-network-based algorithm for locating and identifying particles in reconstructed images [2], a procedure for determining the best-focused depth for each particle, and methods for estimating particle sizes.

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Microballoon and amine sensitization of nitromethane detonation

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Nitromethane (NM) is a widely studied liquid explosive whose detonation properties can be modified using additives. Chemical sensitizers like amines or mechanical impurities such as hollow microballoons significantly alter critical detonation conditions, reaction kinetics, and shock sensitivity. Mechanical additives create hot spots, modifying reaction macrokinetics. This work investigates the combined effect of a chemical sensitizer, diethylenetriamine (DETA), and a mechanical one, glass microballoons, on detonation of NM. The structure of detonation waves was recorded with a laser interferometer, and initiation was studied via high-speed camera. The most pronounced effect of DETA occurs at low microballoon concentrations (≤ 5 wt.%). Adding 2% DETA to such a mixture halves the critical detonation diameter. However, effectiveness of DETA diminishes when microballoon content exceeds 8%. High-speed camera captured the dynamics of hot spot initiation and their growth in the heterogeneous explosive. The study demonstrates the promise of combining amines and microballoons to control the detonation parameters and critical diameter of NM over a wide range.

This study was performed in accordance with the program of Ministry of Science and Higher Education of the Russian Federation No.124020600049-8.

Study of explosive detonation using laser heterodyne technique

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As is well known, the sensitivity of an explosive depends on the charge structure [1]. As the number of inhomogeneities increases, for example, when the explosive grains are crushed, sensitivity can change significantly. This dependence is explained within the framework of hot spot theory, since it is at these inhomogeneities that a chemical reaction develops. The influence of charge structure on the detonation wave should also be present in the case of normal detonation. This study experimentally investigated the effect of the manufacturing method and modification with carbon nanotubes on the mass velocity profile of TNT charges. Samples were manufactured by pressing, layer-by-layer casting, and pressing with the addition of 0.5% single-wall carbon nanotubes. Profiles were recorded using a laser heterodyne technique with high temporal resolution. Two window materials, PMMA and LiF, were used, and data processing was performed using the fast Fourier transform method. A comparison was made with published data obtained in a similar setting.

The study was supported by a grant from the Russian Science Foundation 25-29-00042, <https://rscf.ru/project/25-29-00042/>.

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Kinetics of dimethyl ether high-temperature oxidation: Experiment and numerical simulation

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Dimethyl ether (DME, CH_3OCH_3) is the zero representative of the polyoxymethylene dimethyl ethers (OME_n). These compounds are considered as promising fossil fuels additives. For better understanding of its combustion properties, reliable data on dimethyl ether oxidation is crucial: many reaction rate constants in OME submechs are estimated by analogy with those for DME. In this regard, the major goal of this work was a comprehensive study of the kinetics of high temperature dimethyl ether oxidation. An experimental part was carried out behind reflected shock waves on a high vacuum kinetic shock tube by observing the most important combustion radicals. Time-resolved concentration profiles of atomic oxygen were measured via the precise method of atomic resonance absorption spectrometry (ARAS) at 130.5 nm, which corresponds to the $^3\text{P}_{2,1,0} \rightarrow ^3\text{S}_1$ transition of O atom. Emission profiles of electronically excited OH radicals ($\text{A}^2\Sigma^+ \rightarrow \text{X}^2\Pi$) were measured in the band near 308 nm. Overall experimental conditions implemented in this work are mixtures of 5–10 ppm DME + 15–30 O_2 + Ar, temperatures of 1500–3000 K and pressures of 2–3 bar. Obtained experimental data was used to validate current kinetic models. Based on the comparison results, it was found that the existing DME oxidation models require further improvements to increase their predictive ability. This work was supported by RSCF grant No 25-79-00008.

Shock wave loading of pressed aluminum V-ALEX nanopowder up to pressures of 30 GPa

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The impact response of nanostructured systems are of great interest due to their advantageous characteristics provided by the ultrasmall scale of constituent elements. In this work the shock Hugoniot and shock wave profiles of pressed aluminum V-ALEX nanopowder were obtained in the ranges of mass velocities up to 2.5 km/s and pressures up to 30 GPa. Samples were made of the commercially available aluminum V-ALEX nanopowder. The shock Hugoniot of the studied material deviates from the shock Hugoniots of microsize aluminum with the same initial porosity [?]. This is probably due to the presence of CH₂=CF₂ and CF₃-CF=CF₃ polymers in the composition of the initial V-ALEX powder and their behavior at high pressures. Experimental points were obtained at the contact boundaries with LiF and water windows in the pressure-mass velocity coordinates. Upon unloading from states with pressures less than 15 GPa, the isentropes coincide well with the "mirror" isentropes of solid D16 aluminum. However, upon expansion from states with pressures of 30-25 GPa, the V-ALEX isentropes deviate significantly from the "mirror" isentropes. This may indicate that some processes are occurring in the material compressed by the shock wave.

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Wave-matter coupling mechanisms in cellular-pulsating burning of energetic materials

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Cellular-pulsating burning in energetic materials remains unexplained after six decades of research. Classical continuum theories face three fundamental inadequacies: they cannot explain spontaneous emergence of organized patterns on smooth surfaces (logical circularity requiring initial disturbances), material universality where cellular dimensions maintain constant ratios ($L/\delta_h \approx 10\text{--}15$) and identical pressure scaling ($L \propto P^{-\beta}$, $\beta = 0.5\text{--}0.7$) across vastly different materials, and rapid coordination where cells synchronize within 20–40 ms over 10–20 mm distances while thermal diffusion requires ~ 670 s.

We reveal energetic materials as quantum mechanical information processors through wave-matter coupling spanning ten orders of magnitude. The framework connects macroscopic pressure dynamics with molecular activation via cascaded energy transfer in crystalline structures.

Predictions match observations without adjustable parameters: cell-to-heated-layer ratios (10–15 vs. classical 2–3), synchronization timescales (7–20 ms vs. thermal 670 s), and pressure-scaling exponents (0.5–0.7). Material independence follows from universal wave properties; spontaneous organization emerges through interference patterns; rapid coordination occurs via wave propagation at $\sim 1000\text{--}2000$ m/s.

Mechanistic foundations enable electrically-controlled solid propellants, nanocarbon-engineered combustion architectures, and smart materials combining solid reliability with liquid controllability. This demonstrates quantum transport phenomena governing macroscopic combustion at high energy densities.

Stratified hydrogen–air mixtures

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The study of fast combustion processes in stratified hydrogen-air mixtures is of fundamental importance for enhancing the level of industrial safety. Due to its low density, a hydrogen leak in a confined space can lead to gas stratification and the formation of a combustible mixture layer, creating a risk of fast combustion. The specific risks associated with its extremely wide flammability limits and minimal ignition energy make the development of specialized methods for preventing and suppressing fast combustion in stratified systems critically important.

The paper presents two-dimensional numerical modeling of fast combustion propagating through a layer of reactants, a layer of combustible mixture with an inhibitor additive, or a layer of combustible mixture with a diluent additive. Both a detailed kinetic mechanism and a reduced kinetic mechanism were used to simulate the combustion kinetics of hydrogen in air with an inhibitor additive. A series of cases with different concentrations of diluent and inhibitor additives were studied, which allows for evaluating the effectiveness of various passive and active measures to improve explosion safety at facilities associated with hydrogen use. The development of the mathematical models and numerical simulations were performed using the facilities of National Research Centre "Kurchatov Institute" Federal Science Centre "Scientific Research Institute for System Analysis of the Russian Academy of Sciences" on the topic No. FNEF-2024-0002 "Mathematical modeling of multi-scale dynamic processes and virtual environment systems".

Analysis of elastic-plastic wave during laser shock peening of metal

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One of the perspective methods for surface hardening of various metals and alloys is the laser shock peening (LSP). The technology is based on the effect of generation shock waves and plastic deformation in metallic materials by means of high-energy laser short-pulse impact. Optimization of operation parameters is an ongoing challenge for efficient application of LSP. As a material model, we use the Johnson-Cook (J-C) model with optimized parameters. The J-C model describes the propagation of a shock wave at strain rates orders of magnitude lower (10^3 – 10^4 s^{-1}), however it is widely used by researchers [1] [2] to describe the laser shock peening. The J-C model parameters are fitted using Bayesian calibration directly from the free surface velocity history obtained in LSP experiments at different laser power densities (6 – 19 GW/cm^2). The study was carried out on copper plate thicknesses of 0.25, 0.5, 0.8 and 1 mm. The dynamic loading was made by high energy pulse (10 ns) laser with 1064 nm wavelength. As a result, this approach made it possible to verify the numerical model and describe the propagation of an elastic-plastic wave in accordance with experimental data. Obtained results allow for large-scale numerical study to determine the optimal operating conditions during the LSP. The work was carried out as part of a major scientific project funded by the Ministry of Science and Higher Education of the Russian Federation (Agreement No. 075-15-2024-535 dated 23 April 2024).

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Hybrid combustion model for dust-containing hydrogen–air mixtures in the CABARET-COMBUSTION code

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The CABARET-COMBUSTION code implements the CABARET algorithm for multicomponent reacting gas mixtures, including an approach to resolving sonic points. The code includes a large-scale combustion model for mixed combustible mixtures based on a turbulent flame closure model, a detonation model based on single-stage irreversible chemical kinetics, and a jet combustion model based on a vortex dissipation model. The code has been validated on a number of problems related to the combustion and detonation of hydrogen-air mixtures in open spaces and cluttered channels of various configurations. At the current stage of the work, the code incorporates a hybrid combustion model for dust-containing hydrogen-air mixtures. Within this model, hydrogen combustion is described by a large-scale combustion model, and dust combustion is described by the single-stage chemical kinetics of surface reactions involving oxidation of dust by oxygen and steam. Additionally, the computational model accounts for radiative heat transfer between the gas and dust fractions. This paper discusses the main results of the validation of the presented hybrid combustion model using experiments involving the combustion of graphite dust in hydrogen-air mixtures with varying hydrogen contents.

Numerical modeling using the LEGAK methodology of experiments on radial and end throwing of a copper shell by an explosion of aluminized explosive based on octogen

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In this work, the results of numerical modeling with the use of the LEGAK method of a series of four experiments on measuring the free surface velocity using the photon Doppler velocimetry (PDV) method during radial and end throwing of copper shells by an explosion of a plastisol composition based on octogen with 8 wt. % of Al are presented. It has been shown that using equations of state for explosion products constructed using thermodynamic calculations allows satisfactory agreement between calculated and experimental data on radial and end-on throwing. The fact that the results of thermodynamic calculations conducted under the assumption of non-reactive aluminum were used to construct the equations of state suggests that an 8 wt. % aluminum addition does not have a positive effect on the blasting action of the composition at low expansion rates. Using a special algorithm for determining the parameters of the Chapman–Jouguet point for “porous” compositions, satisfactory agreement with experimental data on the dependence of the propagation velocity of the detonation wave on the initial density of the composition was obtained.

High-speed rotating mirror digital camera for improved accuracy in recording shock and detonation waves

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In this work, the results of developing a high-speed rotating mirror digital camera designed for high-precision recording of fast transient processes are presented. A continuous digital photochronogram is formed using an array sequence of image sensors optically coupled through a mirror system. Experimental results on the registration of shock and detonation waves demonstrate the high resolution and efficiency of the proposed method.

Calibration of the equation of state for TATB detonation products through experiments on the throwing of copper tubes with a diameter of 20 mm

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A comparison is made of various equations of state (EOSs) for detonation products (DPs) used in calculations VNIIEF as well as of experimental data and calculated results obtained with accounting for “ideal” detonation and taking into account the kinetics of detonation of MK using the numerical LEGAK technique. A set of parameters of a new EOS for explosives based on TATB is obtained. It is shown that the proposed EOS allows describing experimental data at large degrees of expansion of DPs. In this work, the results of calibrating a new EOS for DPs for an explosive composition based on TATB are presented. For this purpose, some experimental data on radial and end throwing of 20 mm diameter copper tubes were used. Numerical modeling of experiments was performed using the LEGAC method with the use of “ideal” detonation and MK detonation kinetics. A comparison of various DP EOSs used in VNIIEF calculations was performed. On calculations made with the “ideal” detonation taken into account, all considered EOSs give a deviation from the experiments.

Numerical and experimental study of model valveless pulsejet operation

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The process of energy supply to the gas during burning may be attended by self-exciting oscillations. This phenomenon has been known for a long time and was investigated by Rayleigh. With the aviation and space technology advancement, the problem of the engine destruction due to the occurrence of combustion instability has arisen. However, there is a class of chambers with a benefit of combustion instability – pulsejets. Because the simplicity of its design, engines of this type have been used in aircraft modeling for quite a long time. With the development of pilotless vehicles, a need for simple and cheap jet engines occurs. An experimental model was manufactured to study the working process in pulsejet. It consisted of an air inlet, a combustion chamber, an exhaust pipe and a fuel supply and ignition systems. The diameter of the combustion chamber was 235 mm, the total length of the model was 1750 mm. Propane was used as the fuel. During the operation of the model engine, 57 Hz pressure fluctuations in the combustion chamber were recorded. This frequency was almost independent of fuel consumption. Numerical modeling was performed for the problem both in two-dimensional axisymmetric and three-dimensional formulations. A model of a compressible chemically reactive mixture of ideal gases was used as the medium. During the solution process, a self-oscillation mode was obtained. The frequency was the same as experimental one. Propulsion performance characteristics were also calculated.

Analysis and modeling of flammable gas droplet flows in case of fuel spills and emissions into the atmosphere

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The experimental complex for rapid scanning of turbulent gas droplet fuel flows during their spills, evaporation and condensation of vapors due to emergency and man-made fuel emissions from surface and underwater storage tanks with the formation of explosive and fire-hazardous fuel assembly clouds with digital data transmission via cable or radio channel to the server has been developed and created. Its diagnostic units have been successfully tested in the study of fuel outages in the process of modeling man-made accidents at fuel and energy complex facilities.

It is shown that during large-scale spills and emissions of hydrocarbons in the atmosphere, fluctuating, optically dense and flammable fuel assembly zones can form from a mixture of vapors and droplets with a diameter of 0.5 to 5000 microns.

The created experimental fuel assembly cloud analysis complex can be used in industrial safety control systems for fuel and energy complex facilities, as well as for the development of generators of "instantaneous" aerosol barriers in the atmosphere in the way of man-made and/or accidental emissions of fuels, toxic and radioactive gases.

The result was created while working on the open topic "Development of the physico-technical foundations of methods for measuring the parameters of aerosol and vapor-gas clouds that occur during large-scale accidents at fuel and energy complex facilities and the creation of experimental samples of aerosol cloud diagnostic systems" in accordance with Order No. 5450 dated 12/26/2024.

Passage of the rarefaction wave through the region of metastable states

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At the phase transition boundary (binodal), there is the kink in the isentrope in the pressure-specific volume coordinates. In normal matter, when a compression shock wave (SW) crosses the contact boundary with a less rigid substance, reflected rarefaction wave (RW) propagates in the opposite direction. The matter in the RW occurs in the region of metastable states, where it behaves anomalously. The formation of the rarefaction SW at initial moments of time and the change of the solution of the RW passing with time are shown. Three, successively changing each other, solutions of the RW passing are marked: 1) the self-similar solution with the maximum and constant pressure difference in the rarefaction SW; 2) the transitional solution with the decrease of the pressure difference in the rarefaction SW; 3) the self-similar solution with the formation of the "binodal layer" a layer with fixed hydrodynamic parameters (pressure, density, mass velocity, internal energy), except for the speed of sound.

Plotting a deceleration curve for the explosive products of explosive HMX-based mixture using PDV technique

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Experimental data on shock compression of solids is a primary source of knowledge used to build equations of state; it determines the relationship between pressure, density, and energy, i.e. the Hugoniot. An important task is to obtain the deceleration curve of the explosive products (EP), a function relating pressure and particle velocity in expansion and compression of explosive products. Knowledge of this curve enables determining the state parameters at the Chapman-Jouguet point. It can also serve as the starting point for deriving the EP equation of state. In this work, a deceleration curve for the explosive products of an explosive HMX-based mixture was obtained. The experimental setup was selected to be conventional, with initiation of a plane detonation wave in the explosive by a flyer plate, yielding an initial pressure (37 GPa) close to, but lower than, the Chapman-Jouguet point. At that, both the wave velocity and the free surface velocity at the entrance and exit of the second barrier layer were recorded in sufficiently thick two-layer barrier samples with different shock impedances. The first barrier layer was required for attenuation of the chemical spike. Two-layer samples made of materials with different dynamic stiffnesses were as barriers. The process of the plate movement was recorded using a non-perturbing PDV technique that performed measurements, continuous over time.

Control of the combustion limits of methane-air flames by modifying mixtures with hydrogen

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Currently, the use of an environmentally friendly fuel - methane - is being intensively introduced into technological installations and vehicle engines. This is due to its high mass heat of combustion, industrial availability and moderate cost. However, the methane-air fuel mixture is characterized by a relatively narrow range of combustion modes and reduced flame stability. To overcome these shortcomings, it is possible to add a small amount of hydrogen to the fuel mixture. Due to the short ignition delay and high combustion rate, hydrogen provides increased combustion stability. The work is devoted to the experimental study of the stability characteristics of a pre-mixed methane-air flame with the addition of hydrogen.

The ranges of expansion of the rates of stable combustion of a pre-mixed methane-air flame with different percentages of hydrogen addition under normal and reverse gravity conditions were determined experimentally. The existence of a lean methane-hydrogen-air flame under reverse gravity in contrast to normal gravity conditions was observed. The effect of adding hydrogen on the flame dynamics and shape under normal and reverse gravity conditions was investigated. The influence of hydrogen in ensuring stable combustion of a lean flame under reverse gravity has been shown to be greater than under normal gravity.

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3. Power Interaction with Matter

Testing of plasma-facing components of a fusion reactor

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The study of the effects of a steady-state plasma flow with the characteristics of the edge plasma of a fusion reactor on materials is of significant interest for simulating fusion reactor conditions and material surface modification. The required plasma heat flux density on plasma-facing components for modern fusion reactors is $10 - 40 \text{ MW/m}^2$ with thermal stabilization at 300°C , dictating the need to develop and test heat transfer enhancement systems (both single-phase and two-phase) [?]. Testing structural materials requires a stationary magnetized plasma with characteristics similar to the peripheral plasma of a large tokamak: electron temperature from $1 - 50 \text{ eV}$, plasma density $(1 - 10) \cdot 10^{18} \text{ m}^{-3}$. Such parameters are currently achieved only in a few unique linear plasma installations, one of which is the PLM-M stationary plasma installation developed at the NRU “MPEI”. Samples made of VMP tungsten used for the lining of the ITER tokamak reactor divertor were tested in continuous discharges up to 9 h, with total exposure times of 50–100 h. Power densities of $0.5\text{--}1 \text{ MW/m}^2$ were achieved at plasma electron temperature of 3 eV and electron density of 10^{-19} m^{-3} . Plasma exposure caused the initially smooth tungsten surface to form stochastic, highly porous "fuzz" nanostructures, uniformly filling the entire plasma-facing surface. The nanofiber diameter was 20–100 nm, and the layer thickness was approximately $1.5 \text{ }\mu\text{m}$. This work was supported by the Ministry of Science and Higher Education of the Russian Federation, Project No. FSWF-2025-0001.

Impact of ultra-short laser pulses on metals and two-temperature hydrodynamics

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Over the considerable difference in the masses of electrons and ions, the characteristic time of electron–electron relaxation τ_{ee} (and ion–ion relaxation τ_{ii}) is significantly less than that of electron–ion one τ_{ei} . This allows at intermediate times $\tau_{ee} \ll \tau \ll \tau_{ei}$ electron and ion subsystems to be considered as quasi-equilibrium, with their own temperatures T_e and T_i , which may differ significantly $T_e \gg T_i$ [1]. At higher intensity of radiation or exposure to heavy metals, the substance begins to move noticeably at a substantially two-temperature stage. This makes it necessary to consider the equations of two-temperature thermodynamics [1] together with the equations of motion within a single two-temperature hydrodynamics [2]. The effect of two-temperature on laser ablation, vibrations of a metal film on a substrate and its delamination, etc are considered [3].

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Mandelstam–Brillouin oscillations in specially prepared 3D film metamaterials

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The report presents the results of the [1–4] papers carried out by the team of co-authors, see [1–4]. We use a structured nickel film sprayed onto the glass using a magnetron. The operating mode of the magnetron is chosen so that partial condensation of nickel vapor occurs during its diffusion through argon. The film turns out to be clogged with nickel nanoparticles randomly scattered on the nickel surface [1–4]. This is how our 3D meta-system is formed from a structured nickel film and glass substrate. The Mandelstam–Brillouin oscillations (MBO) is associated with the reflection of light from a traveling acoustic wave in glass. Thanks to a radical increase in the transmittance of the meta-film, it is possible to observe MBO through film. For the first time, the phase of MBO is described. The work is at the junction of nanophotonics, plasmonics and optoacoustics and describes effects in active meta-devices and highly sensitive sensors.

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International FLAP collaboration: From fundamental research to applied solutions in accelerator physics

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FLAP is an international collaboration of researchers from Armenia, Belarus, the UK, China, Russia, and Chile focused on studying the fundamental electromagnetic interactions of relativistic beams to develop novel diagnostic methods and applied radiation sources. This summary highlights key progress at JINR facilities (LINAC-200, MT-25, IREN) toward these goals [1]. Research on radiation mechanisms has yielded a high-resolution coherent transition radiation technique at the MT-25 microtron for femtosecond-to-picosecond longitudinal bunch diagnostics. Studies of superradiant Cherenkov Diffraction Radiation have validated theory and provided a new method for analyzing extended bunch trains [2]. Efforts to find new radiation applications include: 1) proposing an optimized semi-parabolic target geometry to generate a collimated terahertz beam with an on-axis intensity peak, paving the way for compact sources [3]; and 2) conducting experiments at LINAC-200 that demonstrate a viable pulsed neutron source, with achieved neutron fluxes showing good agreement (less than 30 percent) with simulations [4]. These results exemplify how FLAP's fundamental inquiry into radiation from relativistic electrons directly enables practical diagnostics and prototypes for new facilities, enhancing international scientific and technical cooperation.

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Optimization of a synchrotron radiation source in the relativistic self-trapping regime

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Synchrotron radiation sources generated through the interaction of short laser pulses with low-density plasma exhibit unique features, including compact size ($\sim \mu\text{m}$), narrow directivity (~ 10 mrad), ultra-short radiation duration (~ 10 fs), and high brightness. These sources are suitable not only for diagnostics and control in laser-plasma experiments, but also hold practical potential in fields such as security, medicine, microelectronics, and the study of ultrafast physical processes. We examine laser pulses with an energy of 1 J and different durations from 40 fs to 6 fs. Such pulse modifications can be experimentally implemented using the CafCA (TFC) system. Previously we demonstrated that shortening the pulse duration increases the conversion efficiency of laser energy into the total energy of fast electrons by up to 50%. Consequently, an improvement in the characteristics of the synchrotron radiation can be expected.

MeV-level multi-charged ion generation in relativistic laser plasma based on gas clusters

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Laser-driven ion acceleration is a rapidly developing field with significant potential for creating compact sources of charged particles for applications in medicine, materials science, and fundamental research [1]. We compared Kr, Ar, and O₂ clusters for the generation of multi-charged ions with MeV energies under irradiation by a relativistically intense Ti:Sapphire laser pulses ($I \approx 5 \times 10^{18}$ W/cm²) [2]. It was found that for krypton, the optimal average cluster diameter is about 30 nm (pressure ≈ 10 bar), yielding a maximum output of ions with energies of 1-3 MeV and charge states of 2+ to 5+. It can be assumed that the limited observed ionization states are due to recombination during the expansion of multi-charged ions. Home-built magnetic deflection time-of-flight spectrometer allowed estimating the Kr²⁺ ion flux up to 1.4×10^8 ions/(sr·pulse). The obtained results are important for the development of compact accelerated ion sources for applications in radiography, implantation, and studies of fast processes.

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Production of Kr nuclear isomers using laser-driven electrons in a gas-cluster jet

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Nuclear isomers are metastable (lifetime more than 0.1 ms) excited states of the atomic nucleus. Isomeric states are typically observed when a low-lying excited state near the ground state of the nucleus differs significantly from the ground state in spin. Nuclear isomers are currently being actively studied within the framework of nuclear astrophysics, nuclear batteries, nuclear lasers and nuclear clocks. We numerically investigated the optimal conditions for generating nuclear isomers in experiments involving the interaction of intense femtosecond pulses of relativistic intensity with gas-cluster targets. Such experiments are promising as an alternative approach to producing nuclear isomers without the use of accelerators or nuclear reactors. Using 3D particle-in-cell simulations, we investigated the interaction of femtosecond (30 fs) laser radiation with a krypton cluster of 25–100 nm diameter over a wide intensity range. The laser intensity and cluster size optimal for generating the Kr nuclear isomer have been determined, and the calculation results have been verified by comparison with recent experiments. The results obtained are of interest for future experiments on the efficient generation of krypton isomers, and the numerical calculation methods developed in this work can be easily applied to other elements.

Controlled generation of collimated quasi-monoenergetic electron beams

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The development of compact, high-quality electron sources based on laser wakefield acceleration necessitates advanced techniques for precise control over beam parameters. This study presents two approaches for such control implemented on a terawatt laser system. The first approach involves spatio-temporal engineering of the plasma target. Utilising shock waves generated by auxiliary nanosecond pulses in a gas jet, we demonstrate dynamic manipulation of the plasma density profile. This technique enables the production of tunable, quasi-monoenergetic electron beams in the 6–12 MeV range with a narrow energy spread of approximately 2.5 MeV and a divergence below 1.5° .

The second methodology is based on direct wavefront control of the driving laser pulse. We experimentally establish that introducing controlled aberrations, such as astigmatism via a tilted parabolic mirror, significantly alters the laser-plasma interaction dynamics. This manipulation facilitates a transition into the pump depletion regime, resulting in the generation of quasi-monoenergetic beams with higher maximum energies, reaching up to 20 MeV. This dual strategy, encompassing both target structuring and laser pulse shaping, provides a technique for controlling electron acceleration to meet specific application requirements.

Charging wave assisted electron bunch guiding along a laser irradiated wire

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It is known from the experiments upon interaction of short intense laser pulses with a metal wire that it can be used to guide for a long distance an electron bunch (beam) formed from the particles expelling from the irradiated spot. In this report, electron bunch guiding along a wire observed in the experiments is explained by excitation of the pulse type charging (polarization) surface wave and polarization current. This is achieved using three-dimensional (3D) particle-in-cell (PIC) simulations at the sub-mm distance and test particle approach at the macro distance along a wire. Based on the presented physical model of laser-wire interaction, estimates are provided of the emerging surface fields caused by the loss of quasi-neutrality of the target due to the escape of the most energetic electrons heated by the laser pulse. The ability of these fields to guide electrons along the wire is discussed. The presented numerical PIC modeling confirms this physical model. The calculation results demonstrate how electrons, initially oscillating in the Debye sheath, begin to be deflected along the wire under the influence of fields maintained by a positive surface current flowing along the wire. As a result, some time after the end of the laser pulse, two symmetrical electron beams form, traveling along the metal wire (plasma cylinder) away from the focus of the laser pulse on the target.

Peculiarities of water boiling in case of local pulse heating

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Temperature values of three heat exchange modes were determined by the method of controlled pulse isothermal action using a micro-heater in experiments with water. The experiments were carried out at atmospheric pressure in the conductive heat exchange mode with a delay in the beginning of boiling by 50 K, when the conductive heat exchange mode was changed to the probabilistic boiling mode and in the steady-state boiling mode with exceeding the equilibrium boiling temperature by more than 80. In the intermediate temperature range, in addition to the implementation of the conductive heat exchange mode or the boiling of superheated water, it is possible to implement the ultra-intensive heat transfer mode. Using high-speed shooting, it was found that when boiling in the transient zone, that is, in the temperature range from 430 to 460 K, significant thermomechanical vibrations of a pulsed heated wire probe can occur. In this case, the heat flux and heat transfer coefficient are doubled relative to the case of boiling (and subsequent boiling) on a fixed probe. The data obtained are important in the development of miniature devices with pulsed (less than 1 s) and local heat dissipation (about 1 square mm) from a smooth metal wall into water. The investigation has been conducted at the expense of a grant of the Russian Science Foundation (project No. 23-69-10006), <https://rscf.ru/project/23-69-10006>

Electron and proton acceleration in the regime of relativistic self-trapping of an intense Joule-class ultrashort laser pulse

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The results of numerical 3D PIC simulation of efficient proton acceleration from near-critical-density targets irradiated by femtosecond laser pulses with an energy of 2.2 J are presented. The role of the relativistic self-trapping (RST) regime of a powerful laser pulse in the formation of an exploding cavity, where high-charge electron bunches are generated, has been investigated. These bunches create a combined accelerating field a superposition of the double-layer field and the uncompensated charge field of the laser-accelerated electron bunch trapped in the cavity providing proton injection and subsequent directed Coulomb explosion as the cavity passes through the target boundary. For pulse durations of 6–20 fs, the efficiency of explosion-driven ion generation reaches 10–20 MeV/J, exceeding the results obtained with thin-foil targets. Considering the prospects of high-repetition-rate laser systems and gas-jet targets, the obtained characteristics pave the way toward compact sources of protons, deuterons, and neutrons for radiobiology and material science applications.

Nitrogen gas-cluster target as coherent terahertz radiation source under relativistic laser–plasma interaction

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The efficient generation of secondary radiation through intense laser–plasma interaction in gas-cluster targets is of great interest for ultrafast spectroscopy and plasma physics. We report coherent transition radiation in the terahertz (THz) range produced via femtosecond laser interaction with nitrogen cluster targets (irradiation wavelength 800 nm, pulse duration 30 fs, energy up to 310 mJ, intensity up to 5×10^{18} W/cm²) during electron acceleration [1]. For the first time for this type of source, temporal and spatial characteristics of THz radiation at relativistic intensities were measured using electro-optic sampling, the results obtained are consistent with theoretical calculations [2]. Characterization of the emitted radiation reveals highly coherent THz emission with energies up to 10 μ J, spectral bandwidth up to 2 THz, conical radiation pattern with divergence $\sim 20^\circ$, and dominant radial polarization component. Parametric variation of the gas pressure reveals correlated power-law dependencies in the energetic electron charge distribution, THz energy output, and broadband optical emission, pointing to a common underlying mechanism. The coincident generation of THz, electron, and optical radiation in a single interaction region enables multimodal pump–probe studies of ultrafast plasma dynamics.

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Nonlinear optical interaction of 1030-nm ultrashort laser pulses with biocompatible polymers

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An optimized z-scan method is proposed for the correct estimation of the samples nonlinear absorption parameters with possible defects formation under the influence of ultrashort laser pulses [1]. It is shown that at peak intensities $I_0 < 0.65 \text{ TW/cm}^2$ the attenuation mechanism of 1030-nm femtosecond laser pulses in polymethylmethacrylate (PMMA) can be described as fourphoton absorption with a coefficient of $\beta_4 = 35 \pm 5 \text{ cm}^5/\text{TW}^3$, and in polydimethylsiloxane (PDMS) at $I_0 < 0.27 \text{ TW/cm}^2$ - five-photon absorption with $\beta_5 = 750 \pm 90 \text{ cm}^7/\text{TW}^4$. It has been established that the dependence of absorption on pulse duration is nonlinear: increase at $\tau = 250 - 450 \text{ fs}$, followed by a decrease at $\tau = 450 - 1500 \text{ fs}$ and a weak dependence at $\tau > 1500 \text{ fs}$. The maximum nonlinear refraction is observed at $\tau \approx 450 \text{ fs}$ and the values of the nonlinear refractive index and the corresponding self-focusing critical powers are estimated: for PMMA $n_2 = 7.6 \pm 0.4 \times 10^{-4} \text{ cm}^2/\text{TW}$ and $P_{\text{cr}} = 1.4 \pm 0.1 \text{ MW}$, for PDMS $n_2 = 4.6 \pm 0.5 \times 10^{-4} \text{ cm}^2/\text{TW}$ and $P_{\text{cr}} = 2.4 \pm 0.2 \text{ MW}$. The correspondence of the theoretical estimation of the nonlinear focus shift based on them to the modified regions positions in PMMA is shown. The results obtained are relevant for the tasks of precision modification of transparent biocompatible polymers. This research is supported by Russian Science Foundation (project no. 25-22-00488).

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Evolution of the microstructure of the near-surface copper layer during thermal cycling by nanosecond laser pulses

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The mechanisms of surface relief formation upon bulk copper samples under the influence of laser pulses in the preablation mode are investigated. It has been experimentally established that a characteristic system of protrusions and (or) depressions is formed on the surface of samples in local areas near grain boundaries. Molecular dynamic modeling has shown that the main physical reason for the development of the considered relief is the anisotropy of thermal expansion of variously oriented grains (crystallites) during cyclic heating to pre-melting temperatures. It is established that thermomechanical stresses arising in the subsurface layer exceed the yield strength of the material, which leads to irreversible plastic deformation [1].

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The effect of nanoparticles on X-ray generation during irradiation of a solid-state target with an MHz femtosecond laser

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Modern fiber-based MHz laser systems, such as the ANTAUS-10W-40u/250K (1030 nm, 280 fs, 2 MHz, 20 W), make it possible to generate bright microfocused laser–plasma X-ray sources for microscopy applications [1]. Such sources offer convenient operation under non-vacuum conditions. However, contamination by ablation products affects the operational stability of a microfocused source. It has been established that, when femtosecond laser pulses at MHz repetition rates and an intensity of 10^{14} W/cm² irradiate an iron target, ablation leads to the accumulation of particles with diameters of 4–500 nm in the interaction region. This process results in an exponential decrease in the X-ray output with an attenuation time constant of $t \approx 80$ min.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (agreement no. 075-15-2025-458).

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Mid-infrared resonant laser swelling of biocompatible polymers

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Laser swelling is based on the local expansion of polymers irradiated with laser intensities below the ablation threshold, allowing for surface shaping while maintaining optical-quality roughness without post-processing such as wet etching. We used resonant (C–H bonds stretching) near-surface absorption of mid-infrared (3.2–3.5 μm) laser pulses in biocompatible polymers (polymethylmethacrylate, polydimethylsiloxane, hydrophobic acrylic) to form smooth transparent convex (gaussian-like profile) and flat-top tracks with 7–100 μm width (FWHM) and up to 2.7 μm height (top-view phase change about 12 rad at 633 nm) following freeform trajectories on the surface of the sample and confirmed the technological potential of the method by writing a 20 μm -period sinusoidal phase diffraction grating. The onset of swelling was related to reaching the glass transition temperature in the center of a 5–10 times wider laser-heated material redistribution zone, also characterized by a permanently reduced refractive index and the absence of chemical changes detected by Raman microspectroscopy. The technique is perspective for precise manufacturing of dye-free biocompatible polymer phase micro-optic elements including intraocular lenses, flat optics, compound eyes, and other microimaging systems. The results have been obtained as a part of the implementation of state assignment No. FSN-2024-0018.

Study of photophysical characteristics of H3 centers in diamond

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Diamond color centers are in high demand in emerging photonic technologies such as quantum computing, single-photon sources, and magnetic field sensors. H3 centers are of great interest as an active medium for laser generation in the 500–600 nm range [1, 2]. Implementing such technologies requires precise measurements of the photophysical characteristics of the centers, which are currently known from outdated measurements from the 1980s [3].

In this study, the emission cross section was measured using two methods. The first method is based on studying the photoluminescence yield under pumping with ultrashort 150-fs laser pulses of variable intensity. The second method determines the emission cross section based on the luminescence decay kinetics. The values obtained using these methods, $2.7 \times 10^{-15} \text{ cm}^2$ and $2.0 \times 10^{-15} \text{ cm}^2$, agree well with each other and exceed the published value of $1.6 \times 10^{-16} \text{ cm}^2$ by an order of magnitude.

The study was supported by the Russian Science Foundation (Grant No. 25-42-02002).

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Laser sheet forming for straightening and relief forming of metal foils

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This paper examines the use of UV laser (ArF, 193 nm) and IR laser (Nd:YAG, 1064 nm) for metal forming operations, namely straightening and relief forming, of metal foils of 100 microns thick. To determine the influence of scale effects, sample sizes were reduced several times with a scale factor of 2, with the same laser exposure. The feasibility of straightening aluminum, copper, and brass samples for V-bending was determined. Relief forming can be performed for die diameters of 3 to 4 mm up to a depth of 1 to 2 mm. The shock-wave insulated liquid was not used during processing. To increase the proportion of absorbed irradiation and to reduce the ablative effect of the substrate, either black PVC tape was applied to the sample surface, or the area was coated with black dye. Expected stress values were obtained using known analytical equations for bending and forming, as well as theoretical stress values achievable during laser processing. Regimes corresponding to the straightening of the studied materials were determined. Validation of the numerical simulation of the process allows us to gain results for defined boundary conditions, which are consistent with the experimental ones.

Ultrashort pulses of laser-accelerated relativistic electrons for radiobiology and metrology applications

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Using short laser pulses of relativistic intensity, it is possible to generate electron bunches with energies of hundreds of MeV or a total charge at the nC level. Applications of such a source require simultaneously achieving a high charge, electron directionality, and energy, as well as the ability to operate for a long period. Gas-cluster targets can meet all these requirements. We found a suitable configuration and demonstrated its applicability for two relevant applications: 1) radiotherapy of cancer and 2) measuring the duration of electron bunches. We use nitrogen clusters with a radius of 7 nm and a concentration of $2 \cdot 10^{14} \text{ cm}^{-3}$. Irradiation with an intensity of $5 \cdot 10^{18} \text{ W/cm}^2$ produces directed electron bunches with a thermal spectrum of up to 10 MeV and a charge of 2 nC. The efficiency of electron pulses with a peak brightness of 10^{10} Gy/s is evident within the first minute of cancer cells irradiation and is significantly higher than continuous gamma irradiation with a cobalt-60 source of the same average dose rate (2 Gy/min). In the second case, electrons simulate bunches in the accelerator’s photoinjector and are used to develop the method for measuring bunch duration and jitter. The electro-optical method measures the THz transition radiation pulse generated by electrons at the plasma-vacuum interface. Prospects for further optimization of the source and its other applications are discussed.

New approaches in X-ray spectroscopy for experiments with femtosecond PWt laser facilities

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Nowadays, the study of nature and properties of matter (plasma) formed under the influence of ultra-intense laser pulses is of great interest, both from the point of view of fundamental knowledge about the nature of our universe and from the point of view of practical application as a powerful emission source of X-ray, gamma and corpuscular radiation in medicine and applied problems. Plasma formed under the influence of high-contrast laser radiation with an intensity of $1\text{E}21 - 1\text{E}22 \text{ W/cm}^2$ is characterized by short lifetimes of 1 - 3 ps in the extreme state, high energy densities and temperatures of the order of 2-5 keV. One of the most important approaches for investigating the extreme matter state and its emission properties is X-ray spectroscopy with high spectral resolution. It enables the measurement of the most important plasma parameters, the estimation of the degree of ionization and the efficiency of energy conversion into X-rays (energy 0.5–25 keV, wavelength range 0.5–19 Å) and the investigation of various nonlinear effects that occur in ultra-relativistic laser plasmas. In this work, the results of the application of X-ray spectroscopy approaches to the study of steel foil plasmas generated by femtosecond laser pulses with an intensity up to $5\text{E}21 \text{ W/cm}^2$ are presented. This work presents a comprehensive study of femtosecond laser plasma generated by ultra-high-power laser pulses. Experimental results are compared with PIC calculation results. The possibility of the formation of a plasma with an energy density of 1.2 GJ/cm^3 and a pressure of 12 Gbar in the interaction region was demonstrated.

Elastoplastic formation of the laser crater and the rollers around it are completely in the solid state

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In the first works of our team [1, 2], the elastoplastic dynamics of roughness formation on an initially polished flat surface of polycrystalline copper under the action of nanosecond (ns) irradiation was described. Few grains are inside the laser focal spot. The roughness was caused by the inhomogeneous thermal expansion and compression of neighboring crystallites, due to the anisotropy of the coefficients of thermal expansion and creep. Moreover, heating by 100-200 degrees is enough for internal stresses to exceed the threshold of plasticity. Then the results in the form of anisotropic expansion remain in the form of roughness. This paper presents the results of ns heating of a homogeneous layer (not a polycrystal). It is shown that the rollers around the crater are formed in the absence of melting and the Marangoni effect. This is due to the fact that thermal stresses exceed the threshold of plasticity. As a result, the layer is deformed so that a pit (crater) and sides (fringing rollers) are formed in it. Amplitudes of deformations increase with number of ns pulses.

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Spatial-angular characteristics analysis of ion beam profile on ion implanter wafer

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Ion implantation is a basic semiconductor doping technology and imposes increased demands on the uniformity and reproducibility of ion beam parameters. The final acceleration/deceleration system plays a determining role in shaping the spatial and angular characteristics of the ion beam. As part of the TM-200T medium-current ion implanter development, numerical simulation of the ion-optical system (IOS) was performed to assess the compliance of beam parameters with modern requirements. Numerical simulation of the ion-optical system (IOS) was performed in COMSOL Multiphysics. The model accounted for space charge and ion scattering on residual gas for Ar^+ beams in the range of 0.2–270 keV, 0.04–1 mA, and pressures of 5×10^{-7} – 1×10^{-5} Torr. The beam spot size on target remains below 20 mm at 80–270 keV, ensuring doping uniformity. Reducing energy to 40 keV and below broadens the spot to over 30 mm and increases angular divergence to 2–10°, exceeding the $\leq 0.5^\circ$ requirement. Optimizing the deceleration system (80→10 keV) with additional electrodes reduced beam angular spread to 0.1° and provided spot sizes of 6–26 mm at currents up to 230 μA . Pressure increase raises ion losses from 2–8% to 26–35%. The IOS meets spatial profile requirements but shows angular uniformity limitations at low energies, defining optimal operating modes.

Experimental station SHINE for research in the field of nuclear energy technologies at the accelerator complex NICA JINR

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SHINE (Station for Head-on Investigations in Nuclear Energy technology) is a new experimental setup at the Nuclotron slow extraction channel of the accelerator complex NICA. The constructed biological shielding is designated for experiments with high intensity beams of ions from protons to gold in an energy range from hundreds of MeV to 5 GeV per nucleon. The setup is equipped with a set of beam detectors, a data acquisition system, and auxiliary detectors for registration of secondary particles, including neutrons. The main tasks at the first stage of the setup operation are presented. A new collaboration for applied and fundamental research at the station using the capabilities of the NICA accelerator complex is being formed.

New insights into challenging physics of hydrodynamic melt removal at high-intensity nanosecond laser ablation of metals

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Ultradeep removal of metallic materials by high-intensity nanosecond laser pulses in plasma-mediated hydrodynamic regime is well known for the half of century. Multi-micrometer, almost sonic-speed ablation rates per nanosecond laser pulse durations, exceeding by one order of magnitude the few-micrometer near-surface heat affected zone, dense screening ablative plasma and (sub)microsecond-delayed directional sub-sonic expulsion of melt microdroplet fountains are highly promising in nanosecond-laser machining, but still challenging for theoretical explanation. Deep heating of metals by radiative (bremsstrahlung, recombination) and/or shock-wave energy transport were alternatively considered as the key fundamental phenomena, underlying the ultradeep nanosecond ablation process, with the auxiliary physical phenomena like laser peening or cracking in air or water ambients also essentially affecting the performance of the nanosecond-laser micromachining technology. The new experimental insights into this challenging multi-scale physics of hydrodynamic melt removal at high-intensity nanosecond laser ablation of metals are provided and discussed.

Plasmonic ordered submicron substrate for increasing the sensitivity of the Laser-Induced Breakdown Spectroscopy method

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The results of using a plasmonic ordered submicron substrate to increase the sensitivity of the Laser-Induced Breakdown Spectroscopy (LIBS) method [1] are presented. The increase in the intensity of plasma emission is achieved by increasing the local field due to localized surface plasmons of the structure [2]. The vertical deposition method [3] used to synthesize the substrate is simple and allows control of its morphology to tune the excitation wavelength resonance position in a fairly wide range.

Using computer modeling, the dependence of the maximum local field amplification on the excitation wavelength and geometric parameters of the substrate is investigated. The influence of resonant and non-resonant excitation conditions on the intensity and stability of the LIBS signal is demonstrated. Thus, a new method is proposed to increase the sensitivity of the LIBS in studying the elemental composition of liquid samples, that has a number of advantages over existing ones.

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A powerful THz radiation source based on a diamond photoconductive antenna

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Diamond doping has enabled the use of commercially available femtosecond (fs) infrared lasers for optical pumping of photoconductive antennas (PCAs) instead of complex UV fs lasers for generating photocarriers in pure diamond. However, the demonstrated power of the generated terahertz radiation is still far from the maximum achievable level. The main limiting factor is that the electrodes generating the electric field in the diamond substrate are located on the diamond surface, and the bias voltage level is limited by electrical breakdown across the diamond surface (20 kV/cm). Such antennas do not utilize the potential of the diamond substrate to achieve peak power. Their parameters do not exceed those of antennas made of narrow-gap semiconductors. Increasing the peak power requires the implementation of multipole antennas, i.e., antennas containing multiple emitters over a large area. A multiple increase in the THz radiation intensity is achieved by reducing the distance between the electrodes in each dipole and, correspondingly, increasing the intensity of the static electric field. To utilize the full potential of diamond, it is necessary to create conductive structures inside the diamond bulk and operate without exceeding the record breakdown threshold of 10 MV/cm. This work demonstrates the possibility of embedding conductive structures into the diamond bulk to significantly increase the electric field in the antenna. This research was funded by the Russian Science Foundation, grant number 25-19-00796, <https://rscf.ru/en/project/25-19-00796/>.

Long-wavelength shift of an ultraviolet pulse spectrum due to inertial nonlinearity of atomic gases

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Numerical solution of the time-dependent Schrödinger equation for a UV femtosecond pulse (250 nm) interacting with a one-dimensional potential well shows an inertial cubic response with a 200 as delay, comparable to the 800 as UV field period. This intracycle delay shifts the nonlinear polarization spectrum several nanometers toward longer wavelengths.

These results qualitatively explain experimental observations of UV filamentation in air and argon, conducted at the Lebedev Physical Institute (L. V. Seleznev group), where a 1–2 nm long-wavelength shift of the UV pulse spectrum was recorded for both gases. The physical reason of this shift is the inertia of the electronic nonlinear response [1].

Comparison of quantum mechanical modeling results with current alternative approaches to nonlinearity description has shown that explaining such features of ultraviolet filament spectrum transformation, like its asymmetric long-wavelength shift, requires accounting for quantum effects arising from electron-field interaction.

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SCADA “HoroCycle” for automation and control of complex experimental facilities: The profilometer system for beam control in Booster and Nuclotron and beam transportation to collider rings of the NICA JINR accelerator complex

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A hardware and software kit for controlling and monitoring of complex systems of accelerators and experimental facilities is presented. SCADA (supervisory control and data acquisition) “HoroCycle” is an advanced user-friendly tool for development of monitoring and control systems of experimental equipment, acquisition, processing and visualization of experimental data from various detectors. The implementation of SCADA “HoroCycle” for profilometers (based on a microchannel plate) at Booster and Nuclotron of the accelerator complex NICA and ionization multichannel profilometers of beam transfer channels from Nuclotron to the rings of the NICA JINR (Joint Institute for Nuclear Research) collider is reported. The specific feature of the system is the application of advanced algorithms for calibration and analysis of acquired data. SCADA “HoroCycle” is embedded in the programmable logic controller “Fisht” which allows automation of both existing and novel additional equipment.

Conductor influence on a dielectric ring's resonance

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An experimental study and numerical simulation of resonant magnetic fields in a structure consisting of a subwavelength dielectric ring and a straight conducting element have been conducted.

The experimental setup included an antenna and a positioning system for the structure under study. The subwavelength dielectric ring (relative to the incident wavelength) was oriented parallel to the electric field vector. A straight conductor was positioned perpendicular to the wave vector in two configurations: between the antenna and the ring (position "before") and behind the ring (position "after"). A magnetic probe, installed in the plane of the ring, measured the transmission spectrum in the near-field zone.

Configurations with conducting elements of different lengths relative to the resonant wavelength of a single ring were investigated: quarter-wave, half-wave, and arbitrary lengths. Numerical simulation was performed in CST Studio Microwave.

The key result: placement of a straight half-wave conductor leads to strong attenuation of the main magnetic resonance of the ring. The strongest suppression is observed when the conductor is placed **after** the ring (on the probe side). The configuration with the conductor **before** the ring (between the antenna and the ring) also shows significant attenuation, but less pronounced. For conductors of other lengths, a shift in resonant frequencies is characteristic.

The experimental data qualitatively agree with the results of numerical simulation. The possibility of controlling the resonant characteristics of subwavelength dielectric elements using a nearby straight conductor is demonstrated.

Influence of thermoelectric effects in near-surface equilibrium non-ideal tungsten plasma on melt rotation during pulse electron beam heating

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One of the main challenges on the path to a commercial fusion reactor is the damage to plasma-facing components under high steady-state and pulsed thermal loads. For tungsten, chosen as the ITER divertor material, melt motion under intense heating can significantly alter the surface geometry, posing a serious issue for areas with strict shape tolerances. Experiments on the BETA facility showed rotation of solidification patterns on tungsten from pulse to pulse. Subsequent theoretical work demonstrated that thermoelectric effects in an ideal tungsten plasma model are significant enough to drive currents through the target exceeding the beam current. This work presents further development of the model by accounting for plasma non-ideality in the form of ion clustering. The coupling coefficients between thermodynamic forces and fluxes are formulated. It is shown that under the assumption of sufficiently strong clustering, the electrical conductivity is higher than for an ideal unclustered plasma, which aligns with experimental observations for tungsten vapor. Assuming strong clustering, the thermoelectric current increases to values sufficient to explain the experimental data. The influence of magnetic fields is also considered, leading to a redistribution of current from the magnetized low-density plasma region into the central dense near-surface plasma. This provides the correct direction of rotation at the melt periphery, where pattern rotation was observed. Thus, a theoretical model is proposed, applicable for heating by particle beams.

The origin of super-Eddington flares in the high-mass X-ray binary LMC X-4

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LMC X-4 is a bright X-ray pulsar in a high-mass X-ray binary system. It exhibits super-Eddington flares (up to $\sim 10^{40}$ erg s⁻¹) lasting up to few kiloseconds which are accompanied by changes in the pulse profile [1]. Accretion onto NS with a strong magnetic field is accompanied by the transfer of angular momentum between the star and its accretion disk [2]. The origin of the flares is unknown and may be related to the accretion rate increase, as well as to processes associated with the neutron star (NS) — changes in the magnetic field structure or rapid changes in angular momentum. The study of flaring activity is of the greatest interest in the context of fundamental physical processes. This is due to the accumulation of a significant amount of energy and the development of non-stationary processes that lead to the release of this energy in a short time. The goal of this work is to determine the presence of significant changes in the pulsar's spin dynamics and irregularities in the pulse profile shape during flaring activity. In the present paper it has been shown that during flares, no changes in the spin period and its derivative are observed. Changes in the pulse profile are regular with the X-ray flux. Thus, the observed features are caused by changes in the accretion rate, while the structure of the accretion column during flares remains unchanged.

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Laser generated X-ray and gamma-ray sources and their scalings

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Interaction of relativistically intense powerful laser pulses with long-scale plasmas can give rise to effective acceleration of background electrons. In laser wakefield acceleration regime in rarefied plasmas (with electrons concentration much less than critical one) electron bunches with charges from tens to hundreds pC (depending on the nonlinearity of interaction) can be accelerated to GeV or multi-GeV energies. In more dense near critical density plasmas direct laser acceleration regime is possible, with generation of high current (charges from tens nC to several μC), high energy (from several MeV to several hundreds of MeV) electron bunches. Betatron radiation of these electrons can serve as an important tool both for practical applications and also for diagnostic of the process in laser plasma. And if these electrons impinge on a metallic foil converter, powerful sources of bremsstrahlung gamma photons are generated. In order to preliminary (before the launch of respective simulations) estimate parameters of these laser generated sources of x-ray and γ -ray photons, we elaborate theoretical models, which helps one to obtain scalings of energetic, spacial-angular and spectral characteristics of electrons [1, 2] and thier betatron [3] and bremsstrahlung [4] radiation. These models can be helpful for optimisation of the parameters of laser-generated accelerated electron bunches and sources of short-wavelength radiation.

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Promising experimental approach in the intermediate energy region of relativistic nuclear collisions: Existing experimental data and possible research tasks for the NICA JINR accelerator complex

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The analysis of some specific features of secondary particle production with taking into account of collective effects in nuclear matter is performed based on the vast experimental material obtained in the experiments with the bubble chambers. A unified form of self-similarity description of inclusive π -meson distributions in the cumulative and non-cumulative energy region is presented. Promising experiments at the energies of the accelerator complex NICA are considered. Optimal kinematical conditions for finding new regularities in multiparticle relativistic nuclear collisions are discussed.

Raman scattering of two-dimensional magnetic transition metal dichalcogenides

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The present theoretical study is devoted to first-principles calculations of the magnetic transition metal dichalcogenide (TMD) VS₂ within the framework of density functional theory. VS₂ is a distinctive TMD that exhibits intrinsic room-temperature ferromagnetism and metallic-to-semiconducting behavior depending on the structural phase [1, 2]. Despite the intensive research activity devoted to magnetic TMDs in recent years, driven by their promising prospects for applications in spintronics, straintronics, and optoelectronics, detailed theoretical studies of the Raman spectra of VS₂ as a function of the number of layers are still lacking. Thus, for VS₂ with different numbers of layers, the evolution of the positions of Raman-active vibrational modes, as well as the electronic band structure and magnetic properties, is investigated. Although the trends in Raman peak shifts remain similar as the number of layers changes, each number of layers corresponds to a unique Raman spectrum. Therefore, theoretical studies of Raman spectra not only provide insight into the vibrational properties of this material, but also enable unambiguous interpretation of experimental spectra and reliable determination of the number of layers.

The study was supported by the Russian Science Foundation grant No. 25-79-30019, <https://rscf.ru/project/25-79-30019/>.

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RF measurement by Rydberg atoms quantum sensor

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This study is devoted to the development of a recently proposed new technique for measuring electric fields based on the effect of the field on transitions in a Rydberg atom. This technique not only enables absolute measurements without probe calibration, but also introduces minimal distortions into the measured field, as it does not require excitation of conduction electron currents, and the probes used are made of a dielectric. The principle of field measurement in atom-based detectors is that an electromagnetic field causes splitting of the high-lying Rydberg state (the Autler-Townes splitting), with the magnitude of this splitting being directly proportional to the field amplitude. This splitting can be recorded in the electromagnetically induced transparency (EIT) spectrum. Frequency selectivity of the detector is achieved by selecting the Rydberg level number. Rydberg detectors can measure field amplitudes from a few mV/m in a frequency range from tens of MHz to several THz, such as dilute plasma field. The research is supported by the Russian Science Foundation (project No. 25-22-00897).

Characterization of cluster laser plasma using bremsstrahlung X-ray emission and Rayleigh scattering

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When working with cluster plasma, an important task is to characterize its parameters, which is necessary for understanding the processes occurring in the plasma, as well as for computer modeling. We characterize cluster radius, electrons concentration and temperature for several gas-cluster targets (N₂, O₂, Ar, and Kr). To estimate cluster radius Hagena’s scaling laws [1] and experimental Rayleigh scattering (of a 470 nm probe laser beam) are used for a backing pressure 1-40 bar. The plasma temperature is determined from the slope of x-ray bremsstrahlung spectra when target is irradiated by relativistic intensity (5 TW, 30 femtosecond, 800 nm, 5×10^{18} W/cm²). The maximum plasma temperature $T_e = 10 \pm 3$ keV, was observed for Kr at 40 bar pressure. For light atoms (N₂, O₂), the optimal cluster size and plasma concentration were experimentally found at which various types of secondary radiation are generated efficiently as a result of 10 MeV electrons acceleration. When the same cluster size or electron concentration or temperature are achieved for heavy atom targets, the overall efficiency is much lower. Based on the obtained data, the separate effects of gas type, cluster size, and cluster concentration on the bremsstrahlung spectra and other processes were estimated.

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Melting of diamond and tungsten under pulsed laser heating at pressures up to 50 GPa

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Direct observation of diamond melting under high pressures is challenging because diamond is transparent to laser radiation, so direct heating is impossible. This study investigated the melting process of diamond induced by pulsed laser heating of a tungsten plate in a DAC [1]. At a pressure of 50 GPa, during the melting of tungsten at temperatures near 3800 K, a powerful flash was observed, within which the temperature reached 4500 K. As a result of the flash, craters several microns deep formed on the diamond anvils. The diameters of the indentations are 2-3 microns. Analysis of the indentations, conducted using scanning electron microscopy and Raman spectroscopy, showed that there was no graphite phase present. This indicates that melting of the diamond occurred. This research was performed with the financial support of the Ministry of Science and Higher Education of the Russian Federation (FFNS-2022-0008) The research was carried out using the unique scientific installation ‘Laser Heating in High Pressure Cell’ in STC UI RAS [ID: 507563, <https://unu.ntcup.ru>].

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Ivestigation of the Fermi surfase of metals and carbon materials intercalated by metal atoms by doppler broadening positron annihilation spectroscopy under low-background conditions

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The first results of experiments on Doppler broadening positron annihilation spectroscopy of metal and carbon materials, including graphite intercalated by potassium atoms, are discussed. Currently, positron annihilation spectroscopy methods are finding wider application for solving the problems of restoring the electronic structure of matter [?]. Earlier, in the NIKA BNO laboratory, we conducted an experiment to measure the gamma activity of the $\omega = 1454\text{keV}$ line of the $K - 40$ isotope after intercalation of pyrolytic graphite with potassium atoms [?]. We used the Doppler spectroscopy of annihilation peak to determine the radius of the Fermi surface of metals and carbon materials, including graphite intercalated by potassium atoms. Spectra of annihilation photons were obtained for samples of metals Ag , Cu , W , Au , Pb , as well as for polyethylene, pure and intercalated with potassium atoms, pyrolytic graphite.

Detector-grade phosphors: Inorganic materials and halide perovskites for NICA beam profile monitors

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Modern low-background experiments and applied tasks under high radiation fluxes impose a set of requirements on scintillation and luminescent materials (high and stable light yield, predictable spectral characteristics and decay kinetics, optical homogeneity, minimal intrinsic background, scalable and technological fabrication, and long-term stability). In applied facilities, including beam diagnostics at accelerator complexes, additional priorities include spectral matching to photodetectors, the ability to form an active layer, and stability of parameters during operation.

This work presents results on detector-oriented materials in two directions. The first direction concerns inorganic phosphors, for which we analyze the parameters that determine the efficiency of converting excitation energy into an optical signal and the reproducibility of characteristics. The second direction is associated with halide perovskite phosphors, which we synthesize as promising materials for beam profile monitors at the NICA accelerator complex. We discuss technological aspects of forming the active medium, as well as stability and reproducibility requirements necessary for further integration of the material into the readout units of profile monitors.

The reported results refine the criteria for selecting phosphors and active media for low- background detection and beam diagnostics, and provide practical guidelines for transitioning from laboratory luminescence demonstrations to materials suitable for real detectors or diagnostic devices. The study was supported by the Russian Science Foundation (project No.251200322).

Correspondence of the classical radiation reaction to the quantum theory in the strong external fields

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Crystallographic axes and planes provide electrostatic fields strong enough ($\sim 10^3 \div 10^4$ eV/Å) to provide an intense gamma radiation by ultrarelativistic electron (positron) beams moving nearly parallel to these crystallographic directions (channeling radiation - CR). Classical radiation reaction (RR) effects, predicted by the Landau - Lifshitz equation (LL), have recently been studied both experimentally [1] and theoretically [2]. We show that electron's transverse energy damping due to the RR comes from the transitions between the transverse quantum states at relatively low energies, when $\eta = \gamma U_0/mc^2 \ll 1$, and corresponds to the “Schott” term in the classical LL equation for the RR force. $U_0 \sim (20 - 100)$ eV here is a continuous potential depth of the crystal axes (planes), γ in the electron's Lorentz-factor, mc^2 is it's rest mass. It happens for energies less than 10–50 GeV. In the opposite limit of high energies, when $\eta \gg 1$, the transverse energy damping is proportional to the total energy damping and can be calculated within the frame of the quasiclassical Baier-Katkov method which takes into account the quantum recoil due to radiation and influence of spin. The classical analogue of this is the “Lienard” term in the LL equation.

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Comparison of thermal phenomena during the irradiation of sodium chloride and metals with femtosecond laser pulses

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Study of termomechanic ablation of NaCl by 80 fs laser pulses was carried out previously [1]. The phase diagram of sodium chloride, with the use of phase trajectories [2], allows one to evaluate and find the parameters of various thermal processes that arise when laser pulses of femtosecond duration interact with the medium. In experiment, according to our calculation, NaCl is heated to temperature of about 3 kK [2], which is considerably greater than boiling point of the material $T_b = 1738$ K. Note that main temperature processes (melting, ablation) go after the end of laser pulse. Thus, elastic unloading of a heated layer of NaCl with a thickness of $h \simeq 1 \mu\text{m}$ [3] will take place, according to our calculations, in 230–250 ps. After the laser pulse ends, NaCl melts, and a crater of $1 \mu\text{m}$ size has formed [3]. Elastic unloading of a heated NaCl layer $1 \mu\text{m}$ thick has elapsed, according to our calculations, for 230–250 ps approximately. Solidification of liquid NaCl occurs, according to our calculations, in $\simeq 2\text{--}5$ ns. In experiments [1] the liquid phase of NaCl was reliably observed 0.5 ns after the pulse [2].

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Ion beam diagnostics via optical Cherenkov radiation from a CVD-diamond radiator

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In this report, the potential of using optical Cherenkov radiation for diagnostics of the extracted ion beam at the NICA facility is investigated. A CVD-diamond plate, which exhibits dispersion of the refractive index, is used as the Cherenkov radiator. This ensures the formation of a narrow spectral line of radiation when observed at a fixed angle. Using GEANT4 simulation, the spectral characteristics and photon yield of the Cherenkov radiation have been determined, taking into account the configuration of the measurement setup in the SPD test zone. The spectrum is recorded at a 90 degrees angle relative to the beam using a Hamamatsu spectrometer via an optical path with a 4.5 mm diameter lens located 270 mm from the radiator. The simulation results for xenon ion beams with energies of 1–4.5 GeV/nucleon demonstrate the feasibility of monitoring the beam energy and its physical dimension using a single diamond plate. Experimental verification of the method is planned during the Nuclotron run in 2025–2026.

Development of B-10-based detectors for neutron imaging

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Results are presented on the development and testing of neutron detector prototypes based on the boron-10 isotope. One of the detectors is designed for high-resolution neutron imaging and uses a chevron stack of microchannel plates (MCP) with a B-10-coated radiator as a neutron-sensitive conversion layer. Another detector employs a scintillation material with B-10 nanoparticles added to the matrix and is intended for the detection and monitoring of neutron fields. The tests were performed at the IREN facility in collaboration with FLnP JINR.

Two-stage pressurized pyrolytic conversion of biomass into synthesis gas

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Plant biomass is a renewable resource that can be thermally converted first into synthesis gas and then into a range of valuable liquid chemical products. One promising method is two-stage pyrolytic conversion, which combines slow pyrolysis and subsequent high-temperature cracking of volatiles in a layer of solid coal residue. Carrying out the process under excess pressure above 3 MPa offers a number of advantages: reduction in reactors size, reduction in energy losses, simplified scalability, and the production of already compressed gas. Laboratory studies of the process of two-stage pyrolysis of wood were carried out at pressures from atmospheric to 4 MPa with a step of 0.5 MPa. The results obtained show changes in the main process parameters: specific yield of synthesis gas, component composition, content of impurities, moisture and tars. The results confirm the method's high efficiency.

A modulated laser–impedance technique for accurate determination of tissue degradation parameters

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The accurate prediction of thermal damage during minimally invasive laser, microwave, and radiofrequency treatments requires precise knowledge of tissue degradation parameters under extreme thermal conditions. This study presents a novel methodology combining modulated optical heating with real-time electrical impedancemetry to separate reversible (temperature-dependent ionic conductivity) from irreversible (cell lysis, protein coagulation) processes in biological tissue. Liver samples were uniformly heated within an integrating sphere using 970 nm laser radiation, modulated at 0.1 Hz. Simultaneously, the electrical admittance modulus at 10 kHz (sensitive to membrane disruption in the β -dispersion region [1]) and temperature (via highly sensitive fiber Bragg gratings) were recorded. We extracted the temperature coefficient of admittance via Hilbert transform, revealing its dependence on temperature. The irreversible component was then isolated and fitted by the Arrhenius damage model [2], yielding degradation parameters: a critical temperature $T_{cr} = 101 \pm 2^\circ\text{C}$ and frequency factor $\ln(A) = 48.5 \pm 3.8 \ln(s^{-1})$. These results demonstrate better accuracy compared to non-modulated methods, which overestimate reversible effects. The developed technique provides a robust framework for improving treatment planning.

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Raman spectroscopy biomarkers in seminal plasma: Non-invasive detection of male infertility

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The World Health Organization (WHO) defines infertility as a couple's failure to conceive after one year of regular unprotected intercourse. Male infertility accounts for approximately 50% of cases, often independently, with seminal plasma (SP) comprising 95% of ejaculate volume playing a key role in sperm function modulation. Raman spectroscopy analysis of SP offers insights into its molecular makeup, enabling advanced diagnostics for male fertility. In this pilot study, we acquired in vitro Raman spectra (400-1900 cm^{-1} , 532 nm excitation) from 70 dried SP samples. Using Multivariate Curve Resolution (MCR), we resolved spectra into three main components: tyrosine, spermine phosphate hexahydrate, and protein-dominant material. Distinct spectral differences emerged between normal and abnormal samples, notably in peak intensities at 625, 1440, and 1008 cm^{-1} , achieving 79% specificity and 95% sensitivity for classification. To our knowledge, this represents the first investigation identifying biochemical Raman markers distinguishing normal from abnormal SP per WHO criteria (sperm count, motility, morphology). These results advance male infertility diagnostics and underscore the need for novel strategies in reproductive health.

Determination of the temperature of spontaneous boiling-up of water in emulsions on a micro-dimensional heater

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Visualization of fast-flowing processes of heating, convection and boiling under conditions of pulsed isothermal action $T_{st}(t-t_1) - T_0 = \text{const}$, where t_1 is the duration of temperature increase of a micro-dimensional wire heater from the initial value T_0 to the experimentally set value T_{st} . The objects of the isothermal exposure study were water, aqueous emulsions of rapeseed oil ether and their mixtures. The subject of the study was the temperature-time range of the instantaneous heat transfer coefficient (MCT) from a miniature heater undisturbed by boiling into the above-listed samples with an initial temperature of T_0 with a step-by-step change in the T_{st} value. It is shown that at atmospheric pressure with the duration of thermal stabilization $t = 1$ s in the case of deionized water, the temperature range $T_{st}(t) - T_0$ undisturbed by boiling corresponds to the degree of overheating relative to the liquid-vapor equilibrium temperature T_s in 70-80 K. Water droplets in vegetable oil emulsions reduce the values of overheating of the starting oil at $t = 100$ ms by 50-200 K in the range of 0.1 – 10 wt. The investigation has been conducted at the expense of a grant of the Russian Science Foundation (project No. 23-69-10006), <https://rscf.ru/project/23-69-10006>

Beam profile monitor system in the extraction channels of the Nuclotron–NICA complex using proportional ionization chambers and the HOROCYCLE SCADA system

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Proportional ionization chambers have been designed and manufactured for monitoring heavy ion beams in the transfer channel from the Nuclotron synchrotron to the NICA collider at JINR. Nine stations are installed along the line: two on the northern branch to the collider, five on the southern branch, one before the beam splitting point, and one portable unit, providing flexible coverage of the extracted beam section. The proportional chambers measure horizontal and vertical beam profiles in a pulsed extraction mode, allowing a detailed characterization of the transverse structure of the heavy ion beams. Data acquisition and control of the high-voltage power supply, detector positions, and working gas mixture are integrated into a dedicated SCADA system that provides unified control of the diagnostics infrastructure. The system has demonstrated reliable performance in commissioning runs and has been successfully used to tune the extraction and transport of the beam into the collider, thereby supporting stable operation of the NICA complex.

Directional freezing of suspension as a new approach to increasing the efficiency of laser-induced breakdown spectroscopy in elemental composition studies

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A new method for enhancing Laser-Induced Breakdown Spectroscopy (LIBS) [1] signal intensity in elemental analysis of nano- and submicron particles in suspension has been demonstrated. The method is based on the displacement of particles by a solidification front during the process of directed freezing of a liquid [2]. As a result, a densely packed layer of particles is formed on the surface, which leads to an increase in the intensity of plasma emission when interacting with laser radiation. It is shown that the morphology of the resulting layer of particles can be controlled by changing the freezing configuration. The results of increasing the sensitivity of the LIBS method for various suspension freezing configurations, as well as the influence of particle concentration on the efficiency of the process are presented.

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Optimization of a cluster-based laser–plasma source of Kr K_α radiation for X-ray diffraction

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Cluster targets irradiated with a fs laser make it possible to generate bright pulsed (≈ 2 ps) characteristic-radiation sources [1] that can be used for pump–probe experiments with high temporal resolution. Key features of such targets include stability, the absence of contamination, and the ease of controlling their parameters and composition. In this work, to achieve a higher krypton K_α yield, the cluster diameters (50–60 nm) and concentration ($\sim 10^{12}$ cm $^{-3}$) in the jet were optimized by adjusting the pressure (30–40 bar). The jet was irradiated with femtosecond (30 fs) 5 TW laser pulses focused to 5×10^{18} W/cm 2 . As a result, for ~ 60 nm krypton clusters a K_α photon yield of 3×10^8 photons/($4\pi \times$ pulse) was achieved. Changing the atomic composition of the clusters to argon enabled K_α (3 keV) generation with a yield of 2.5×10^8 photons/($4\pi \times$ pulse). The Bragg diffraction peak of this K_α line from an Si(111) crystal was measured. Estimates of the parameters of an X-ray pump–probe experiment were made, and the optimal characteristics of the developed source for this experiment were determined.

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The titan alloy surface laser ablation treatment

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The fiber laser IPG YLM-QCW-100 type with a pulse duration from 0.1 to 50 ms and the pulse energy up to 15 J with a repetition rate of 20 kHz at the 1070 nm wavelength with a movable platform was used to treat the surface of three titanium alloy samples of dental implants for continuation of our works [1–4]. Laser surface treatment of all three titanium alloy samples were performed at the laser radiation power density of 869 MW/cm². As a result, areas of the sample surface appeared with a pronounced presence of titanium oxide on the surface (the appearance of a golden color) and an increased structurally of the laser-treated surface was observed.

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On the possibility of preliminary estimation of the time resolution of pulsed ionizing radiation detectors using the SARMA-300 flaw detector

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The time resolution of pulsed ionizing radiation detectors is defined by the duration of the detector impulse response to a delta radiation pulse and characterizes the ability of the detector to register fast transient radiation processes.

This work presents a methodology for the registration and processing of the impulse response obtained using a diamond detector with a subnanosecond response time and a reference measuring instrument, the SAD1M diamond dosimeter, which has high sensitivity and deliberately lower time resolution. A pulsed x-ray flaw detector, SARMA-300, and a powerful ultrashort-pulse laser producing bremsstrahlung radiation were used as sources of ionizing radiation. Radiation pulses generated by the SARMA-300 flaw detector were experimentally recorded using the diamond detector and SAD1M detectors. It was shown that the detector output signal contains contributions from both bremsstrahlung and characteristic radiation of the x-ray tube anode, leading to an increase in the impulse response duration and distortion of its temporal shape.

Based upon the obtained results, a methodology for the preliminary estimation of the time resolution of the detectors is proposed. The method is based on simultaneous registration of the impulse responses of a reference detector and a detector under development to the radiation of the SARMA-300 flaw detector, followed by signal processing using convolution.

Hybrid remote sensing of temperature and emissivity distribution on the surfaces of heated bodies

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During remote temperature measurements in limited frequency ranges of thermal radiation, it can be assumed that the emissivity of a heated body is independent of the wavelength. It is known as the "gray body approximation." In general, it does not hold and can be represented by a polynomial approximation. "Hybrid method" [1] (a) reduces multidimensional minimization to one-dimensional; (b) provides a means for graphical control of the minimization process and the derivation of analytical expressions for measurement errors; (c) reduces computation time. The hybrid method combines linear and nonlinear regression algorithms. It is also shown that the application of the hybrid method in temperature measurements using multispectral cameras allows for the investigation of melting processes and phase transitions at high pressures and temperatures. As examples, results from experiments on the melting of nickel aluminide are presented [2]. This research was performed with the financial support of the Ministry of Science and Higher Education of the Russian Federation (FFNS-2022-0008) The research was carried out using the unique scientific installation 'Laser Heating in DAC' in STC UI RAS [ID: 507563, <https://unu.ntcup.ru>].

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First-principles modelling of spin current in Co/NiCu spintronic terahertz emitters

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Spintronic terahertz emitters convert an ultrafast laser-driven spin current into a broadband THz transient via spin-orbit mediated spin-to-charge conversion. Here we model the spin-current generation in a Co/NiCu bilayer emitter by combining a thermodynamic diffusion formalism with the *ab initio* approach. Spin-polarized electronic configuration of a Co/NiCu supercell is obtained from density-functional theory calculations. The electronic structure for each spin channel is then propagated separately through the semiclassical Boltzmann transport equation with BoltzTraP2 [1] to extract spin-dependent electrical conductivity and Seebeck coefficients. Spin current and its dependence on temperature gradients and channel asymmetry were further calculated with the phenomenological framework proposed by Fognini *et al.* [2]. The resulting workflow provides a first-principles route to quantify interfacial influence on the spin-current in bilayered metallic THz emitters.

The study was supported by the Russian Science Foundation (grant No. 25-79-30019, <https://rscf.ru/project/25-79-30019/>).

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Generation of terahertz radiation by irradiating small Ar and Kr clusters with relativistic laser pulses

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Powerful, single-period terahertz (THz) pulses are a promising modern tool for non-ionizing and non-thermal effects on substances. The search for a method for generating THz pulses from subpetawatt lasers without output saturation and without contamination of optical elements is relevant. One method is laser-plasma sources. Laser pulses varying in power ($5 * 10^{18} \text{ W/cm}^2$) were emitted from a gas-cluster target obtained by successively elongating a gas (Ar or Kr) through a conical nozzle in a vacuum. Rayleigh scattering and changes in gas pressure were used to control cluster size. Due to rapid ionization, charge separation, or electron acceleration, the THz energy collected by a Golay cell and electro-optical detection was closed. It was found that, depending on the gas pressure and, consequently, the cluster diameter and plasma concentration, different THz generation mechanisms predominate. At pressures above 8 bar, THz are generated by accelerated electrons crossing the plasma-cluster medium boundary [1]. As the pressure decreases by 5–8 bar, the contribution of accelerated electrons is reversed, but a new THz maximum appears. The second maximum THz yield corresponds to a cluster radius of 2–4 nm. Measuring the spectrum, polarization, and directivity of THz suggests a quadrupole generation mechanism [2]. This study aims to better understand the processes of high-power THz generation in laser-induced cluster plasmas.

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Exothermic reactions during low-temperature pyrolysis of plant biomass

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Biomass includes wood and agricultural waste, peat, and various types of human waste. Torrefaction (low-temperature pyrolysis) is used to improve the consumer properties of biomass and involves heating the feedstock in an inert environment to a temperature typically ranging from 250–300 °C. Torrefaction increases the energy density and grindability of the biomass, while reducing its hygroscopicity and susceptibility to decay. Biomass torrefaction can be accompanied by significant heat release due to exothermic reactions. Control of process temperature is crucial to obtain a product with the desired properties. This study analyzed the behavior of plant biomass during low-temperature pyrolysis using analytical equipment and a laboratory fixed-bed reactor. Samples of waste from the forestry and agricultural industries (pine sawdust and sunflower husk) were used in the experiments. DSC analysis (SDT-Q600, TA Instruments) revealed the temperature ranges of exothermic processes of thermal decomposition of the materials. The lab-scale study was conducted using a thermally insulated reactor with indirect (through the wall) heating and thermocouples located at various cross-sections. Experiments revealed the presence of zones in the material layer with temperatures significantly exceeding the reactor wall temperature during the thermal processing of sunflower husks. The obtained experimental data will be useful in designing a technology for producing biofuels based on the process of biomass torrefaction. This work was supported by the Ministry of Science and Higher Education of the Russian Federation (State Assignment No. 075-00270-26-00).

Modeling and diagnostics of uranium gamma activation after passage through 10 cm of iron

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A comprehensive numerical approach to the remote detection of fissile materials concealed behind massive metallic shielding using laser-driven gamma radiation is presented. In the first stage, Particle-In-Cell (PIC) simulations are employed to model electron acceleration from solid targets irradiated by an ultra-short laser pulse (20 fs, 2 J). The resulting electron energy and angular distributions are used as input for GEANT4 simulations of bremsstrahlung generation in a converter, demonstrating a high conversion efficiency into gamma quanta with energies above 7.5 MeV.

The propagation of the high-energy gamma flux through 7–10 cm thick iron shielding and its interaction with a uranium-containing sample are subsequently investigated. Photoneuclear reactions, including (γ, n) , $(\gamma, 2n)$, and (γ, f) , are modeled, leading to the emission of fast and delayed neutrons as well as the formation of neutron-deficient unstable nuclei.

It is shown that under high gamma fluence conditions a measurable induced radioactivity is produced, giving rise to characteristic gamma lines persisting for minutes to hours after the laser pulse. This delayed emission enables spectral measurements in a time-separated (“slow”) regime with reduced prompt background. A combined analysis of energy-dependent signatures and time windows (prompt, neutron-induced, and activation-related components) demonstrates the feasibility of a laser-driven gamma activation method for selective identification of the composition and burial depth of shielded fissile materials.

Propagation of a monoenergetic beam of relativistic electrons in vacuum

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The generation of high-current, narrow-beam relativistic electron beams has become possible due to the use of low-density foamed polymers, which allow the generation of relativistic electrons through the interaction of an intense laser pulse with a plasma with an electron concentration close to the critical value. The high absorption of a relativistic-intensity laser pulse in a plasma with a near-critical density and the efficient direct laser acceleration (DLA) of electrons in the plasma channel result in the efficient conversion of laser energy into the energy of the relativistic electron beam.

The work considers an analytical model of the propagation of a monoenergetic homogeneous beam of relativistic electrons with an infinite longitudinal length and a finite initial distribution radius in a vacuum. The parameters of the model were selected based on experimental data obtained using the PHELIX laser facility [1]. The results of PIC simulations for this problem showed qualitative differences from the experiment, with a monotonic increase in concentration with increasing beam radius, which does not match the experimental maximum concentration on the beam axis. This increase in concentration towards the edges of the beam is due to the peculiarities of relativistic mechanics, which postulates a limit on the speed of light. This phenomenon was previously studied in an analytical paper [2] using the model of an infinitely long beam.

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4. Methods of Mathematical Modeling

Accounting for gamma-quanta absorption reactions in the ^{235}U fission chain reaction modeling by the TPT3 program

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The TPT3 program is developed in Dukhov Research Institute of Automatics for the parallel radiation transport simulation on the multicore CPU and GPGPU architectures with SIMD instructions. One of its key features is the simplified voxel geometry beneficial for massively parallel computations. The TPT3 physics covers nearly all aspects of interactions of atomic ions and neutrons with matter in a wide energy range and can transport the weighted particles. The weighted particles transport lets simulate nuclear chain reactions with high multiplication factors in almost arbitrary nuclear fuel assemblies subdivided in billions of Cartesian cells – voxels, characterized by a uniform concentration of nuclear isotopes, and take into account the nuclear fuel burnout and the dynamic modification of the simulation environment by the isotopes of the fission products.

The weighted simulation results for the chain fission reaction with the fuel burnout modeling in the uranium cube are presented. The time dependences of the numbers of neutrons, gamma-quanta, generated fission fragments, and generated heavy uranium isotopes, produced in the radiation capture reactions, are calculated. The results are compared for the simulations with and without photo-fission, Bethe-Heitler reactions, and the Compton scattering. The degree of the nuclear fuel burnout, growth constant, heavy isotopes generation, and the time before explosion are calculated as functions of the uranium cube edge length.

Quantum properties of radiation propagating in a nonlinear medium

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Photon statistics can have a significant impact on the propagation of radiation in a nonlinear medium. In addition, the presence of nonlinearity affects photon statistics: in particular, dephasing, which is a consequence of nonlinearity, destroys the coherence of radiation. Within a classical description of such a system, it is difficult to explicitly account for the statistical properties of fluctuations and the possibility of spontaneous radiation generation; therefore, such a description may be inaccurate. To overcome these difficulties, we employed a standard procedure [1, 2] based on a field-theoretical approach using the Schwinger–Keldysh diagrammatic technique and Legendre transformations in the Nambu representation for bosons propagating in a medium with quartic nonlinearity in the field. We show that coherent radiation in this system provides parametric pumping of squeezed radiation. This effect appears already in the first order with respect to the interaction between radiation modes. At the same time, in the second order in the interaction, dephasing effects arise that suppress the parametric pumping process described above and destroys the squeezing. Moreover, dephasing is enhanced with increasing radiation power. The competition between the pumping and dephasing processes makes it possible to estimate the propagation length at which generated radiation squeezing is maximal.

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Ab initio study of the optical properties of LiF

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Refractive index n of LiF is investigated using DFT + G_0W_0 + BSE (Bethe-Salpeter equation). We report $n(\omega; \rho, T)$ as a function of photon energy ω , density ρ and temperature T . The $n(\rho, T)$ curve is of importance for VISAR and PDV experiments, where n varies with pressure and temperature along the Hugoniot. Our results show the best agreement with experimental data among existing theoretical studies for LiF, supporting the reliability of fully theoretical optical predictions. To obtain accurate n , it is shown that an accurate band gap (14,2 eV) and excitonic effects are required. The former is obtained with the quasiparticle G_0W_0 method, which captures correlational screening in the Coulomb system. The latter is included via BSE. Excitons reproduce adequate optics for LiF. We show that neither the band gap nor optical absorption is reproduced by the hybrid HSE functional. We account for ionic-temperature effects using QMD and quantify the resulting uncertainty in n , which is novel. The study covers $n(\rho, T)$ up to $P \approx 210$ GPa. QMD Hugoniot calculations indicate melting near $P \approx 140$ GPa under the Lindemann criterion, consistent with studies suggesting melting instead of a B1-B2 transition. Finally, the band gap increases with pressure even until $P \approx 1400$ GPa, contradicting metallization scenarios proposed so far.

Keywords: LiF; *Ab Initio*; Refractive Index; VISAR; PDV; DFT, QMD, G_0W_0 +BSE; Excitons; Ionic Temperature

Influence of the Jacobian spectrum on the accuracy of neural network approximation of chemical kinetics

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In this work, a neural network was trained to reproduce the temporal evolution of a hydrogen–oxygen mixture, generated using a reduced chemical kinetic mechanism. After training, the prediction errors (MSE) were analyzed over the test dataset, and the trajectories were divided into percentile groups according to the neural network error. For each percentile group, the local Jacobian matrix of the original kinetic system was reconstructed along the corresponding trajectories and the eigenvalues were used to find the local stiffness of the governing equations. The largest eigenvalues associated with fast radical reactions remain in a narrow range from 10^{15} to 10^{17} for both well and poorly predicted samples. For accurately predicted trajectories, the smallest eigenvalues are typically of order 10^4 , resulting in stiffness ratios in the range from 10^7 to 10^{14} . In contrast, for poorly predicted trajectories, the smallest eigenvalues decrease down to 10^1 to 10^{-2} shifting extreme stiffness ratios up to 10^{16} to 10^{21} . This result demonstrates that the spectrum of the Jacobian has an impact on neural network errors and the magnitude of the smallest eigenvalues can be used as an indicator of cases where models are expected to lose predictive accuracy.

The work was carried out within the framework of the state task of the Scientific Research Institute for System Analysis of the National Research Centre “Kurchatov Institute” on the topics FNEF-2024-0001 and FNEF-2024-0002.

Violation of the Luttinger's theorem in fractional Chern insulators

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In this work, single-electron excitations in a fractional Chern insulator are investigated. The fractional insulator phase can be described in terms of weakly interacting fractionally charged quasiparticles. However, it was theoretically predicted [1] that the electron is a stable excitation in this strongly correlated liquid. Moreover, using the Luttinger theorem [2], one can show [3] how electronic correlations are related to the low-energy physics of the fractional quantum Hall effect. The focus of this study is to explore the physics of the fractional quantum Hall effect in lattice systems (fractional Chern insulators) using the Luttinger theorem [2].

In this study, we analytically and numerically demonstrated a violation of this theorem in the fractional quantum Hall phase, which is associated with the emergence of the Green's function zeros within the single-particle gap. In particular, this leads to a deviation of the many-particle Chern number C from the value N_3 , which is an invariant and works well in the integer quantum Hall effect.

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Transfer learning for predicting the dynamics of complex atomic ensembles

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Multiscale modeling based on machine learning (ML) enables the exploration of broad regions of thermodynamic parameters. For multicomponent systems, calculations of transport properties or phase diagrams remain challenging. Creating training datasets for ML interatomic potentials (MLIPs) requires thousands of configurations, making the process inefficient. A solution is multi-stage transfer learning. First, accurate but slow graph neural networks, pre-trained on large quantum-chemical databases, are used. They are then fine-tuned on a small number of *ab initio* DFT configurations. Then, fast fully connected networks are developed, enabling calculations with millions of atoms. This approach reduces the volume of training data by an order of magnitude and allows adapting MLIPs to non-standard DFT. The methodology was applied to predict a phase diagram for the Ca–Fe–Ni ternary system over a wide pressure range (0–500 GPa), which is of interest to materials science and geophysics. Fine-tuning of the MLIP potential required 10,000 DFT configurations. The results are consistent with known data. Stable CaFeNi phases were predicted. The study demonstrates the effectiveness of transfer learning for accurate and resource-efficient modeling of complex atomic systems under extreme conditions [1].

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Aluminum K-line radiation source topology in Z-pinch experiments with explosive magnetic generator

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Investigation of powerful fluxes of soft-X-ray radiation (SXR) at the implosion of multi-wire cylindrical arrays has been carried out in RFNC-VNIIEF for many years. The arrays are powered from laboratory and explosive current sources. With current amplitudes 5-5.5 MA and implosion times 0.75-1 microseconds in experiments with an explosive-magnetic generator (EMG), equipped by an explosive opening switch (EOS), the efficiency of generating a K-line of aluminum was 35 percent of the total radiation energy, which is comparable to the results obtained on the Saturn facility with a Z-pinch implosion time 80 ns, and significantly higher than the efficiency of generating a hard radiation component on the Sphinx facility with an implosion time 800 ns. This work provides the numerical studies of the aluminum K line radiation source topology in Z-pinch experiments with EMG performed within the framework of the radiation magnetohydrodynamic codes FLUX-3D and FLUX-rz.

Emulation of microstructure evolution in FCC metals using machine learning methods based on continuous modeling and experimental data

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The microstructure of metals and alloys directly influences the strength and mechanical properties of the material and plastic deformation processes [1]. This paper presents the creation of a dataset from the results of numerical simulation and experiment. The first part of the data was obtained using cellular automata [2] and continuum modeling. The second part was obtained from microstructure images of deformed pure aluminum and copper samples.

The resulting dataset was used to train a machine learning emulator for the microstructure evolution process in metals. The emulator consists of convolutional and recurrent layers. To compare the performance of different machine learning emulator architectures, dimensionality reduction methods (UMAP [3]) were used instead of convolutional neural network layers for processing the input data. The study was supported by grant No 24-71-00078 from the Russian Science Foundation, <https://rscf.ru/en/project/24-71-00078/>

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MDcraft: A modern framework for accurate and scalable molecular dynamics simulations

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Molecular dynamics has become a cornerstone of computational materials science, enabling the study of complex phenomena ranging from atomic diffusion to extreme-condition response. As simulation demands grow, so does the need for frameworks that combine physical fidelity, algorithmic efficiency, and scalability. Here we present our novel code Mdcraft which addresses this need by integrating quantum-accurate, machine-learned interatomic potentials into a modern, high-performance architecture. The code features a high-level Python interface for usability and rapid prototyping, while its core algorithms—implemented in modern C++—ensure computational efficiency. Designed for contemporary high-performance computing environments, MDcraft supports MPI-based distributed parallelism with dynamic load balancing and leverages shared-memory parallelism within nodes. This combination of accuracy, flexibility, and scalability makes MDcraft a powerful tool for researchers across materials science, condensed matter physics, and computational chemistry.

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Structural transformations in liquid selenium under high pressures

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It has long been known that simple liquids undergo a continuous structural transition with changes in temperature or pressure. Research conducted over the past few decades has shown that some simple liquids undergo a discontinuous first-order phase transition, which is accompanied by changes in density, entropy, and structure, and is known as the liquid-liquid phase transition (LLPT). In 1989, Academician V.V. Brazhkin published the article [1], in which a conductivity jump and a volume effect were observed, which suggests that the semiconductor-metal transition is a first-order phase transition. In this work, liquid selenium at high pressures was studied using density functional theory (DFT), machine learning interatomic potentials and molecular dynamics. There were conducted series of calculations along different isotherms, the radial distribution function and the dependences of volume, coordination number and isothermal compressibility on pressure along these isotherms were analyzed. No volume jumps were observed, which indicates the absence of a phase transition of the first order. A minimum is observed on the radial distribution function, which indicates a change in the local structure of the liquid (structural transition). Also there is a kink on the isothermal compressibility, which may be a consequence of a structural transition.

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Diffusion of atomic impurities in liquid lead-bismuth eutectic using a machine-learning potential

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Reliable data on the diffusion of atomic impurities in liquid lead–bismuth eutectic (LBE) are critically important for predicting corrosion, mass transfer, and chemistry control in lead-cooled nuclear systems. However, direct experimental measurements of impurity diffusion coefficients in LBE — for steel components (Fe, Cr, Ni), oxygen, and hydrogen — remain extremely challenging. Reported experimental values exhibit wide scatter and strong dependence on indirect modeling assumptions [?].

Ab initio molecular dynamics (AIMD) provides an accurate description of liquid LBE and impurity–melt interactions [?], but its application to diffusion studies is restricted by the limited time and length scales accessible in first-principles simulations. Machine-learning interatomic potentials trained on ab initio data overcome these limitations by reproducing near–first-principles accuracy while enabling long-time, large-scale simulations required for statistically converged diffusion coefficients. The development of such potentials can be further automated using active learning techniques, allowing systematic and reliable modeling of impurity transport in liquid LBE.

In this work, we develop a machine-learning interatomic potential for the lead–bismuth eutectic system using an active learning approach. The resulting potentials are applied to calculate diffusion coefficients of atomic impurities — Fe, Cr, Ni, O, H, C, and Ti — in liquid LBE.

Seepage flows through porous media under extreme conditions

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This work considers the modeling of the process of liquid flow through a porous medium under microgravity conditions, as well as in the presence of chemical reactions or combustion. The behavior of liquids in microgravity is significantly different from the behavior in terrestrial conditions. Many processes on space stations are associated with fluid flow: heat pipes, life support systems, fuel supply systems. For predictive modeling of orbital hydromechanics processes, it is necessary to develop appropriate mathematical models based on experimental data. Studies of the flow of liquids due to capillary forces are very relevant for space technologies. This investigation discusses experiments on imbibition of a porous medium during parabolic flights. The results of processing experiments when the flow occurred in a porous medium formed by glass balls are presented. A study of fluid flow in a Hele-Shaw cell is proposed for modeling microgravity conditions. A series of experiments devoted to the study of unstable multiphase flow in a Hele-Shaw cell with inserts located inside the cell is described. A stable flow in a Hele-Shaw cell is also considered, the problem of mathematical modeling of such flows are discussed. Capillary instability is described and the mechanisms of its occurrence are investigated. The poster presents the results of numerical modeling of a three-phase unstable flow in a Hele-Shaw cell. The development of the mathematical models and numerical simulations were performed using the facilities of National Research Centre "Kurchatov Institute" Federal Science Centre "Scientific Research Institute for System Analysis of the Russian Academy of Sciences" on the topic No. FNEF-2024-0002

Enhancement of quasi-stationary magnetic fields via of the plasma density profile in the regime of relativistic self-channeling

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A novel approach to enhance quasi-stationary magnetic fields generated via the inverse Faraday effect during the self-channeling of circularly polarized laser radiation at relativistic intensity is investigated in this work. A previously established method [?] is generalized for constructing self-consistent, stationary, axisymmetric laser-plasma structures to the case of transversely inhomogeneous plasma density distributions. To circumvent discontinuous solutions encountered elsewhere [?], a small regularization parameter with the physical meaning of temperature is introduced. This method describes filaments formed during the relativistic self-focusing of circularly polarized radiation [?, ?]. As a result, the generated axial magnetic field increases by more than an order of magnitude compared to the homogeneous case and becomes comparable in magnitude to the magnetic field of the laser wave. This opens a path toward achieving teragauss-level quasi-stationary fields at laser intensities of 10^{26} W/cm².

Data-driven planning of computational workflows for materials modeling

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Modern materials modeling increasingly relies on complex computational workflows that integrate quantum-mechanical (QM) calculations, molecular dynamics, and machine-learning interatomic potentials. These approaches enable the prediction of a wide range of material properties at a fraction of the cost of experimental measurements. However, certain properties — such as the liquidus temperature — remain computationally demanding and can even exceed experimental costs. This challenge motivates the continued development of strategies to further reduce the computational expense of such workflows.

There is an often overlooked opportunity to improve the efficiency of such workflows through more effective use of computational resources and improved handling of non-convergent QM calculations. We present a data-driven approach for the automatic planning of computational workflows. Gaussian process regression is used to predict efficient calculation settings, identify unreliable calculations, and select appropriate computational resources. Our approach is validated on melting-point and thermodynamic property calculation workflows based on active learning of the Moment Tensor Potential [1], demonstrating improved robustness and reduced time-to-solution.

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An automated workflow for thermodynamic properties prediction via Bayesian free energy reconstruction

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In this work, an automated tool for predicting thermodynamic properties of materials is developed. The framework reconstructs Helmholtz free-energy surfaces [1] from molecular dynamics simulations using Gaussian Process Regression [2] with zero-point energy corrections [3]. It accounts for statistical uncertainties, mitigates finite-size effects, and provides uncertainty-aware estimates of thermodynamic quantities. The framework is applicable to both solid and liquid phases within NVT and NPT ensembles. An active learning strategy is employed to adaptively select simulation points, reducing computational cost while preserving accuracy [4]. This enables systematic analysis of thermodynamic and mechanical properties, as well as melting behavior. The approach is tested on cubic structures using classical and machine-learned interatomic potentials [2].

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A Bayesian methodology for constructing ternary phase diagrams: The LiF–NaF–KF system

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This work presents a Bayesian methodology [1] for constructing phase diagrams of salt systems, applied to the ternary LiF–NaF–KF system. The approach combines Gaussian process regression with molecular dynamics data that include statistical uncertainties. Molecular dynamics are performed using a Moment Tensor Potential [2, 3], parametrized via active learning on density functional theory calculations. The Gibbs free energy surfaces are reconstructed from their temperature and composition derivatives using Gaussian process regression, and the phase diagrams are obtained via the common tangent method.

The methodology was validated on the binary NaF–KF system and successfully applied to the ternary LiF–NaF–KF system, with both diagrams showing good agreement with experimental data. Computational costs were below 20,000 CPU hours for the binary diagram and approximately 100,000 CPU hours for the ternary diagram, demonstrating the scalability and practical applicability of the approach.

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Choice of poisson solver for axisymmetric PIC model for Hall Effect Thruster

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Today, numerical simulation plays a crucial role in studying plasma behavior in Hall-Effect Thrusters. Commonly used methods include fluid, hybrid and kinetic models. While the first two methods require less computational resources, their application is limited because plasma is non-Maxwellian in Hall Thrusters.

Axisymmetric numerical models are widely used in calculations. In most models, only the plasma region is considered that leads to the following problem: it is necessary to use either a uniform rectilinear grid and trivial geometry of a thruster or non-uniform curvilinear grids. The first approach sacrifices accuracy of simulation, and the second one complicates particle and force weighting and the solution of the Poisson equation for electric potential. Moreover, distribution of electric field inside thruster's dielectric walls is usually neglected. The authors developed an axisymmetric PIC-model with a uniform rectilinear grid, which computational domain includes both plasma region and thruster's walls. Operating speed and effectiveness of parallelization of several Poisson equation solvers using a multiprocessor computational cluster were studied in this work.

Research of relativistic nuclear interactions using the properties of Lobachevsky space

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A large number of problems in relativistic nuclear physics are focused on finding patterns in the behavior of relativistic multiparticle systems. The collision of relativistic nuclei leads to the production of many particles and a complex interaction pattern.

This work studies the interaction of a neutron with a proton target in a hydrogen bubble chamber at neutron energies ranging from 1 to 5 GeV. During the processing of tracks in a bubble chamber, the values of the momentum and scattering angles of secondary particles are determined. Using the measured values of the energies and momenta of the reaction products, the geometry of Lobachevsky is used to calculate their velocities, the defects of the triangles formed by the velocities, and the angles of the triangles in Lobachevsky space. A program code has been developed to calculate the rates of reaction products, angles, and triangle defects in Lobachevsky space for all processed $np \rightarrow pp\pi^-$ events.

In addition, the effective masses of the reaction products are calculated using the energies and momentum projections. By comparing the distributions of rapidities in Lobachevsky space with the effective masses, the masses of the resonances associated with neutron-proton interactions can be determined. In the $np \rightarrow pp\pi^-$ reaction, a portion of the events involving the production of Δ^- resonances exhibits a characteristic peak at a mass of 1.232 GeV. The greatest interest of this study is expected in the consideration of configurations in the space of relative rapidities. Events are considered when one of the reaction product particles acquires a relatively small momentum against the background of a large momentum of the incident neutron. This area of relativistic nuclear interactions is not fully studied.

Neural network approximation of chemical kinetics with variable time and physics-enriched dataset

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We present a neural network approach for accelerating simulations of hydrogen–air combustion kinetics using compact neural network architecture with fully connected layers and residual connections adapted for multidimensional time series prediction. The method incorporates logarithmic data renormalization to enhance sensitivity to small concentration changes near zero, coupled with standard scaling, and introduces a recurrent training strategy where multi-step predictions (up to 30 steps) are embedded into the loss function to minimize error accumulation during autoregressive inference. We also show that enriching the training set with states near temperature inflection points identified via second derivatives reduces mean squared error by 45% (from 1.8×10^{-3} to 1.0×10^{-3}) without increasing dataset size or model complexity. The resulting lightweight network (5 layers, about 32 000 parameters) achieves accurate approximation of species concentrations and temperature evolution for hundreds to thousands of integration steps ahead. This approach demonstrates significant potential for integration into multidimensional computational fluid dynamics simulations of reacting flows.

The work was carried out within the framework of the state task of the Scientific Research Institute for System Analysis of the National Research Centre “Kurchatov Institute” on the topics FNEF-2024-0001 and FNEF-2024-0002.

Coupling algorithm for finite volume and smoothed particles methods

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To expand the range of solvable problems, it is proposed to use an algorithm that combines the Finite Volume Method (FVM) and Smoothed Particle Hydrodynamics (SPH) [1], allowing simultaneous calculations with different methods in different spatial regions. For the FVM, a Riemann solver is used that takes into account the speed of the contact discontinuity [2], as is the case for SPH. The time step is chosen based on the Courant criterion for each method, and integration is performed with a common minimum time step. Virtual cells and particles are created near the interface, with data recalculated from the real particles and cells, respectively. To ensure a smoother and more accurate transition of material from the cell region to the particle region, as well as to maintain the continuity of the SPH medium, an algorithm for generating virtual particles has been developed and implemented. This algorithm uses a combined approach, integrating the Particle Shifting Technique (PST) [3] and free-surface detection [4] methods. This comprehensive algorithm generates particles and then shifts them at a small, computed speed relative to the material boundary, which allows for an even distribution of particles across the problem domain and ensures the continuity of the density field. The results of applying the algorithm are demonstrated through a series of test cases that show sufficient accuracy in preserving mass, momentum, and energy flux as the material transitions through the interface region.

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Resolving the In–Au–Hg phase diagram using Bayesian learning

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This work investigates In–Au–Hg amalgams for applications in mercury gas-discharge lamps. Temperature-composition phase diagrams are constructed to identify amalgam compositions with elevated melting temperatures, enabling higher lamp performance. Gaussian process regression is applied to molecular dynamics (MD) simulation data with quantified statistical uncertainties, allowing the reconstruction of Gibbs free energies as functions of temperature and composition. MD simulations are performed using the Moment Tensor Potential (MTP) [1]. The developed methodology yields phase transition boundaries with associated confidence intervals in the thermodynamic limit for both binary [2] and ternary systems. The approach is applied to the construction of the In–Au_{0–0.33}, In–Hg_{0–0.2}, and In–Au_{0–0.33}–Hg_{0–0.2} phase diagrams. The resulting phase diagrams show good agreement with available experimental data [3–5], up to a systematic temperature shift attributable to the accuracy of the DFT calculations used for MTP training.

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Numerical study of tungsten fuzz tendrils behaviour during rapid heating

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Fuzzy nanostructures form on tungsten surfaces under helium plasma exposure, relevant to conditions in fusion devices [1]. The growth of such helium-filled nanostructures can raise the probability of unipolar arc ignition [2], thereby enhancing the erosion of plasma-facing materials. Herein, we use molecular dynamics simulations to investigate the atomistic behaviour of individual fuzz tendrils under rapid heating. The heating rates considered in the simulations are based on theoretical estimations of the fuzz thermal balance [2], which account for Joule heating and reduced thermal conductivity [3]. The simulation results identify a critical heating rate of ~ 100 K/ps order. Exceeding this rate leads to the explosive destruction of a nanowire. At lower heating rates, a more gradual structural change via bubble rupture and sublimation is observed. Furthermore, by modelling the interaction between an exploding nanowire and a neighbouring stable structure, we demonstrate that the high-energy flux of ejected material from the primary structure transfers sufficient kinetic energy to the adjacent nanowire to destabilize its internal helium bubbles, initiating a secondary release event. These findings reveal a detailed atomistic mechanism for the initiation and potential cascade propagation of explosive thermal damage within tungsten fuzz layers. The work was supported by the Russian Science Foundation (grant No. 22-12-00274-P).

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Two-dome superconductivity and Coulomb correlations in FeS

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Tetragonal FeS exhibits a puzzling “double-dome” superconducting phase diagram under pressure. To elucidate the microscopic origin of this phenomenon, we investigate the electronic structure evolution of FeS using a combination of Density Functional Theory and Dynamical Mean-Field Theory (DFT+DMFT). Unlike standard DFT, this approach explicitly treats dynamic electronic correlations, which are essential for accurately capturing the orbital-selective band renormalization in iron chalcogenides.

Our results demonstrate that electronic correlations play a crucial role in driving an electronic Lifshitz transition. The DMFT calculations provide a description of the Fe $3d_{z^2}$ orbital evolution, confirming that the sudden appearance of a hole pocket near the Γ point is responsible for the reemergence of superconductivity in the second dome. The inclusion of dynamic self-energy effects corrects the critical pressure of the transition compared to non-interacting models. Currently, calculations regarding the specific symmetry of the superconducting gap are in progress, utilizing the full interacting Green’s function to solve the linearized gap equation in the correlated regime.

The DFT+DMFT calculations was supported by the Russian Science Foundation (Project No. 24-12-00024). The DFT calculations were supported by the Ministry of Science and Higher Education of the Russian Federation for the IMP UB RAS and youth project No. 12-25. The theoretical analysis of electronic structure was supported by the Foundation for the Advancement of Theoretical Physics and Mathematics “BASIS”.

Model of thermal shock-induced damage in graphite

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The transition to combustion of carbon materials in rocket and space technology components is preceded by intense surface heating, which may be accompanied by the generation of a stress wave (thermal shock) with subsequent ablation, delamination, or spalling. The heating rate and the nonlinear dependence of the thermal diffusivity coefficient on temperature, which itself depends on the porosity of the carbon material, determine the possibility of the metastable heat localization effect in the blow-up mode. This study is devoted to analyzing the patterns of heat localization and their connection with thermal shock mechanisms in carbon-carbon materials under intense thermal exposure. Assessing the thermal strength of a material under conditions of metastable heat localization typically requires solving a wave problem, since the blow-up time is close to the acoustic time, using specific criteria. An approach to the numerical simulation of the nonlinear thermoelasticity problem taking into account damage accumulation in graphite and considering the temperature dependence of thermophysical and physico-mechanical properties is presented. Boundary conditions for the occurrence of blow-up regimes are defined, and the dynamics of metastable localization are investigated. A comparison of numerical results with an analytical solution has been conducted, confirming the existence of two heat propagation regimes: wave and blow-up.

The influence of the effective number degrees of freedom on the effective transfer coefficient in a heterogeneous medium taking into account its geometric and topological properties

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This work presents operations for homogenizing a stationary heat conduction equation with a Fourier-type equation of state. The heterogeneous medium is two-phase and occupies a bounded region. The method of conditional moments [1] and the generalized derivative formalism [2] are used, taking into account the configuration of the internal boundaries of the heterogeneous medium. The mechanism for the appearance of characteristic phase sizes in the effective coefficient is analyzed: the ratio of the characteristic phase sizes and the ratio of the characteristic phase size to the size of the heterogeneous medium region under consideration (the averaging size), which is a consequence of using the generalized derivative formalism and considering a bounded medium. The reason why the geometric characteristics of a heterogeneous medium influence its topological properties is analyzed, leading to the appearance of an effective number of degrees of freedom during the propagation of the field under study. The effective coefficient is obtained for a space of arbitrary dimension. This approach is focused on describing heterogeneous media with a hierarchical structure, as well as the formation of defects and cracks.

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Weak decaying collective-excitation approximation for strongly coupled Coulomb and Yukawa one-component plasmas

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Multiparticle systems with pronounced long-range interactions exhibit the following characteristics in their density fluctuations. The dynamic structure factor of such systems is characterized by the near absence of a central (Rayleigh) peak and consists primarily of side (Brillouin) peaks, which correspond to propagating collective excitations. Simultaneously, high-density systems are also marked by significant interparticle spatial correlations. Consequently, traditional approaches based on the mean field approximation [1] become inapplicable. It was recently demonstrated in [2, 3] that an approach based on self-consistent relaxation theory can yield analytical expressions describing the diverse spectral filtering (DSF) spectra of strongly coupled Yukawa and Coulomb plasmas across a wide range of wavenumbers. In this paper, we present an algorithm that simplifies the previously obtained expressions for the DSF, describing collective excitations in these systems from the hydrodynamic regime down to scales on the order of the interparticle distance. This new approach is termed the weak decaying collective-excitation approximation.

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Numerical modeling of gas dynamic body flow using polyhedral grids

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Currently, research is being conducted on gas dynamics processes in flow around bodies [?, ?] using unstructured polyhedral meshes. The developed algorithms and mathematical methods provide a wide range of possibilities for using such types of grids to obtain high-quality and fast results due to modern algorithms for constructing grid structures. Growing interest in polyhedral meshes is driven not only by their ease of use but also by a number of identified advantages, discussed in [?]. In this paper, a study was conducted on the accuracy of calculating gas-dynamic fields in the region close to the boundary layer, when calculating using unstructured polyhedral meshes. Based on the simulation results on a coarse mesh, the total pressure values in a group of cells are significantly higher (by 10%) than the free-stream total pressure. It was found that significantly coarser meshes improve the accuracy of calculating the total pressure in the specified region. This effect was absent when performing first-order calculations and arose when switching to second-order. An assessment was made of the impact of the selected turbulence model on the simulation results: Inviscid, Laminar, Spalart-Allmaras, Transition SST. Some calculations were performed on an unstructured hexagonal mesh. As a result, when using the hexagonal mesh, the total pressure parameters were calculated correctly throughout the entire computational domain.

Development and validation of neural network potentials for V–Ti–Cr alloys

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This work reports the development and validation of machine-learning interatomic potentials for the vanadium alloy V–4Ti–4Cr [1]. The training dataset was obtained from DFT (VASP) and includes Ti and Cr concentrations up to 15 at.% and high-temperature configurations. We show that configurations with anomalously short interatomic distances and large forces can destabilize fine-tuning of descriptor-based models; we also observed signs of non-physical behavior when using MatterSim for pretraining-based data generation. We fine-tuned and benchmarked NEP [2], DeepMD-DPA3 [3], and MACE potentials, obtaining comparable RMSE for energies, forces, and stresses, and then used a two-stage transfer learning workflow to train a fast DeePMD-SE potential for large-scale MD. Physical validation employed two-phase melting and stress–strain simulations at ambient pressure to estimate the melting temperature, Young’s modulus, and Poisson’s ratio; the results are consistent across potentials and agree reasonably with available experimental or literature data [4]. The work is supported by the Russian Science Foundation (project No. 25-29-01649).

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5. Physics of Low Temperature Plasma

Modeling of meteoroid ablation in dense layers of the Earth's atmosphere

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The report discusses the features and results of the experimental modeling of meteoroid ablation. Experiments on modeling the ablation of meteoroid matter are produced using a generator of high-temperature high-velocity gas flows [1]. The conditions in the heated gas stream generated by the experimental setup are close to those corresponded to the low-velocity bolides fall in the lower atmosphere. In experiments, material of artificial fusion crust and optical ablation spectra were obtained for samples of Tsarev, Chelyabinsk, Calama009 ordinary chondrites and terrestrial basalt. The correspondence of the artificial fusion crust obtained in the experiment and the fusion crust formed during the flight of the bolide in the Earth's atmosphere is shown. The experimentally obtained emission spectra of the stony meteorites ablation within the optical range are compared with the spectra of stone meteorites observed during their passage through the Earth's atmosphere, as well as with the spectra obtained in other laboratories using experimental plasma installations [2, 3].

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Dynamical properties of small clusters of Janus particles in RF-discharge plasma

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In recent years, several studies on mesoscopic systems of active particles have been conducted [1, 2]. However, the questions concerning structural transitions in these systems, energy transformation within them, and their evolution under various external conditions remain open. In this work, an experiment was conducted to study finite systems of active particles in an RF discharge. A voltage with a frequency of 13.56 MHz was applied to the parabolic electrode; then, melamine-formaldehyde particles, half-coated with molybdenum, were introduced into the discharge. The particles were charged by electron and ion fluxes and levitated above the center of the electrode. They were illuminated by a laser. The laser power was varied from 0.08 W to 1.2 W. The particle motion was recorded using a high-frequency video camera.

It has been discovered that the analysis of the particles' dynamics (kinetic energy and localization areas of the particles, fractal dimension of their trajectories) can be indicative of their composition. Specifically, we were able to distinguish different types of particles in the system under study: 1) Janus particles with a shifted center of gravity; 2) uncovered particles / particles with partial coating.

This work was supported by the Russian Science Foundation (project no. 25-12-00406)

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Self-propulsion of suspension microdroplets driven by active microparticles dynamics

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A numerical study of hydrodynamic flows generated within droplets of active particle suspensions is performed. Using a two-phase mathematical model that combines a Lagrangian description of individual particle motion with an Eulerian description of the fluid flow, the research examines how droplet geometry and active force intensity influence the development of self-consistent flow patterns. The results demonstrate that in a spherical droplet where each particle is subjected to an active force with random orientation, a stable spindle-shaped vortex flow emerges, spanning the entire fluid volume. When the active force is uniformly directed, a toroidal flow pattern develops, accompanied by a significant shift in the system's center of mass. The study establishes that the active force parameters critically determine the flow regime, driving a transition from chaotic motion to organized collective behavior. These findings help identify fundamental hydrodynamic principles that govern the self-propulsion mechanisms of active suspensions.

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Thermodynamic limit of the Coulomb system in the model of a bounded one-component plasma

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We present a molecular-dynamics study of a bounded one-component plasma (BOCP): identical classical ions embedded in a uniform neutralizing background and confined by a rigid, specularly reflecting spherical wall. By simulating a sequence of sufficiently large BOCP systems and quantifying finite-size trends, we extrapolate key quantities to the thermodynamic limit. In particular, we obtain the electrostatic energy per ion over a wide range of the Coulomb coupling parameter $0.03 \leq \Gamma \leq 1000$ with a typical relative uncertainty of $\sim 10^{-3}$. The resulting energies are systematically lower than several modern periodic-boundary Monte Carlo datasets at $1 \lesssim \Gamma \lesssim 30$ (by roughly 0.5%), while converging to the same weak- and strong-coupling limit at low and high Γ , respectively. Beyond the conventional total energy, we introduce two separately convergent quantities — the excess interionic energy and the excess ion-background energy — which together yield the ionic compressibility factor and thus an ionic equation of state not directly accessible in standard periodic OCP simulations. Using this EOS as a reference, we propose an improved Γ -dependent real-space cutoff for interionic forces in LAMMPS workflow, and demonstrate that kinetic and interfacial measures can depend sensitively on cutoff choice. These results provide a high-precision benchmark for validating plasma simulation methods and for calibrating approximate free-energy models across weak to strong coupling. The BOCP framework also offers a controlled route to extract thermodynamic derivatives from particle simulations without relying on periodic-image conventions.

Features of localization of polarized sources of microwave radiation flashes of extended spark discharge

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A radio measuring system based on ultra-broadband antennas (10 MHz - 6 GHz) is demonstrated, which makes it possible to study the spectral and spatial characteristics of radio emission sources in an extended (about 60 cm) high-voltage (about 1 MV) laboratory spark discharge [1]. In the report, we show that high-frequency radio emission has a complex spectral and temporal structure and manifests itself in the form of many short (lasting less than 1 ns) bursts. These spikes are observed at the stage of voltage growth in the discharge gap and when it reaches its maximum values. We also present the results of radio interferometric measurements, during which the discharge regions associated with the appearance of high-frequency radio emission were localized with centimeter accuracy [2]. Our study shows a close relationship between radio emission and intense streamer formation in the discharge gap [3]. The work was carried out with the financial support of the Russian Science Foundation (grant 23-19-00524).

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Structures of active Brownian particles in a monolayer of colloidal plasma under laser irradiation

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This work presents experimental results on structural transitions in a monolayer of active Brownian particles. The experiments were conducted using synthesized melamine-formaldehyde (MF) particles confined in a radio-frequency (RF) plasma discharge. The particles were coated with a light-absorbing layer via magnetron sputtering, enabling localized heating under laser irradiation and thereby increasing their kinetic energy of motion. A transition from an ordered to a disordered state was observed in a system far from thermodynamic equilibrium, proceeding through an intermediate hexatic state [1]. The analysis of this transition employed pair correlation functions, bond-angular correlation functions, the two-dimensional static structure factor, and a characterization of topological defects. The findings indicate a two-stage melting scenario consistent with the Berezinskii–Kosterlitz–Thouless (BKT) theory [2] for two-dimensional systems in thermodynamic equilibrium. This work was supported by the Russian Science Foundation (Project No. 25-12-00406).

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Generation of neutron radiation in an inertial electrostatic plasma confinement tube

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Systems based on inertial electrostatic plasma confinement (IEC) are sources of continuous neutron radiation. The main parameters affecting the level of the generated neutron flux are the discharge ion current, the ion-accelerating voltage at the cathode, the pressure of the working gas in the system, the geometry of the electrodes and their temperature. Most IEC systems studied worldwide are pumped-out designs with cylindrical or spherical geometries of the anode and cathode. Systems of sealed IEC design are of particular interest, as they are simpler to operate and do not require the use of vacuum pumping and gas-filling systems. Furthermore, such systems enable safe operation using tritium. At Dukhov Research Institute of Automatics an IEC tube consisting of a system of cylindrical electrodes, which allows efficient extraction of ions from ion sources and their acceleration towards the cathode to implement nuclear fusion reactions, has been designed.

The operation of individual units of the IEC tube was investigated. An experimental dependence of the generated 14 MeV neutron flux on various parameters, such as the voltage on individual units of the tube and the gas pressure inside it, was obtained. During continuous operation of the tube, lasting approximately 100 hours, stable neutron flux generation at the level of 5×10^7 n/s was achieved.

Spectral density of oscillations of inertial active Brownian particles in a harmonic trap

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This work presents initial results of a theoretical and numerical study of inertial active Brownian particles confined by an external trapping potential. The dynamics of such systems is governed by the interplay between thermal fluctuations, dissipation, inertia, and active driving, which leads to nontrivial fluctuation spectra and deviations from classical Brownian behavior. Particular attention is paid to the spectral density of particle fluctuations as an informative and experimentally accessible characteristic of active systems.

At the current stage, the spectral properties of particle motion have been analyzed within a generalized stochastic framework that accounts for translational and rotational inertia. Analytical expressions for the spectral density were obtained in a number of limiting cases, revealing the role of inertial effects in shaping the frequency dependence and characteristic spectral features. These analytical results were systematically verified by extensive numerical simulations performed over a wide range of model parameters. Good agreement between analytical predictions and numerical data was observed.

The performed analysis demonstrates that inertia leads to qualitative and quantitative modifications of fluctuation spectra, including shifts of characteristic frequencies and changes in spectral amplitudes. The obtained results provide a solid basis for further investigation of interacting active particle systems and for the development of non-invasive methods for reconstructing dynamical parameters of active matter from spectral measurements.

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Advanced probe diagnosis system development for the low-temperature plasma plumes investigation

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The work presents the simulation and experimental verification of a new method for measuring the ion energy distribution function and the fraction of double charged ions. Existing measurement methods require the geometric dimensions of the probes to match the parameters of the plasma being studied, which makes it impossible to perform accurate measurements with a single probe under different conditions. [1] [2] [3] The new HDR RPA presented in this paper allows measuring the energy spectrum of ions in a six-order-of-magnitude wider range of plasma concentration compared to a traditional gridded probe, with a maximum error of 1.5% in determining the energy peak. The new Wien filter can work with a sensitivity of 0.2% for the fraction of double charged ions in plasmas with ion energies ranging from 100 to 2000 eV. The paper presents the new simulation method of the probes' performance in plasma and the results of experimental verification of simulation in a range of plasma concentrations from 10^{12} to 10^{18} m^{-3} . The experiments have proven that the simulation method is correct and new probes work correctly.

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Separation of microparticles in a quadrupole trap with variable pulse fill factor

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An experimental study and numerical calculation of the separation of microparticles in a quadrupole electrodynamic trap with rectangular voltage, operating in air at atmospheric pressure, have been conducted.

The experimental study was performed at various fill factors K_p in the range of 30–50%. For each K_p , experiments on particle release were carried out, and particle size distributions were measured. In parallel, numerical calculations of stable retention regions were performed for particles with diameters of 5, 10, 20, and 50 μm .

It is shown that at $K_p = 50\%$, the calculated retention regions for particles of different diameters overlap, forming a single continuous q/m range. This explains the experimentally observed simultaneous presence of particles of all sizes in the trap. As K_p decreases to 45%, 40%, 35%, and 30%, the stability regions narrow and shift, leading to the selective release of particles of specific sizes. The experimental particle distributions at each change in K_p qualitatively agree with the calculated retention regions.

On plasma formation from tungsten nanofragments via electrical explosion

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Plasma-surface interaction in fusion devices result in intence surface modification e.g. in growth of layers of helium-filled nanowires of tungsten - fuzz. Spontaneous ignition of arcing at such a surface occurs much easily. Explosive-electron emission pulse-periodic functioning results in plasma formation via electrical explosion of micron-scale areas of W-fuzz layer.

We have calculated the estimation of tungsten fuzz nanostructure electrical resistivity due to electron scattering by helium nanobubbles distribution to be 0.265 mOhm cm for single nanowire and 1.92 mOhm cm for the fuzz layer (of 1/20 density) [Tsventoukh and Kulagin 2025 Phys. Plasmas 31, 092509]. It allow us to build "avalanche" model for the helium-filled nanowires electrical explosion with energy transfer from primary exploding nanowire to the secorndary via explosion products [Tsventoukh 2025 Phys. Plasmas 32, 052502].

One need to determine the explosive plasma composition id est average charge of the ions (electron and ion densities) fraction of neutral metal nanoclusters in net plasma produced

Two-temperature model [Tsventoukh 2021 Phys. Plasmas 28, 024501] has been upgraded to include calculated resistivity of W-fuzz in the following form $\rho_{1nw} = m_e/n_e^2 \times v_2 \times (1 + T/15kK)$, where v_2 is the frequency of electron scattering by helium nanobubbles in the nanowire, giving at 300 K the value of resistivity about 0.265 mOhm cm. Approximation of the average ion charge $Z = T_e \times [1 - (lgn - 20)/5]/eV$ gives average charge of tungsten ions reaching values of about +3 for typical explosion conditions. Work supported by RSF grant 22-12-00274-P.

Ion accumulation by spherical clouds of microparticles

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The parameters of the plasma of a low-pressure electric discharge in neon with spherical clouds of charged microparticles [1,2] have been calculated. The behavior of ion accumulation efficiency [3] indices by microparticles as a function of gas concentration and microparticle concentration was studied. For the efficiency index reflecting the ability of the cloud to accumulate ions per microparticle [4], the value of the limiting concentration of microparticles in a dense Coulomb sphere is obtained, exceeding which leads to a decrease in the considered value. The pressure and temperature of the experimental medium corresponding to the formation of spherical clouds were compared to the parameters of the standard atmosphere at different altitudes. It is shown that microparticles of larger size, located at the same height with smaller ones, have a higher ions accumulating ability. It is found that for all particles of the considered size the efficiency of ion accumulation by a microparticle increases with increasing height. It is found that smaller microparticles with decreasing height lose the ability to accumulate ions effectively faster. Comparison of calculation results for air and neon plasmas showed that at the same atmospheric height the accumulating ability of microparticles in air plasma will be only not much lower than in neon plasma.

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Domains of equal efficiency of ion trap in a complex plasma of a glow discharge

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Issues related to the control of ion parameters in plasma are relevant in the implementation of plasma-chemical reactions with their participation. In this work, the parameters of low-pressure glow discharge plasma in neon with microparticles are determined, at which in the cloud of charged microparticles, domains of the same energy efficiency of accumulation of ions are formed. The efficiency of such an ion trap is determined based on the calculation of a number of indicators related to a single and the cloud as a whole [1, 2]. The formation of domains with equal ion retention efficiency is inherent in dissipative synergetic plasma systems [3,4]. The feedback is formed by plasma processes that compensate for plasma losses on microparticles. In this regard, the cloud of microparticles represents the main link in the control chain of plasma-chemical processes, where the efficiency domains define the areas of control of parameters [5]. The feedback depth is determined by the degree of microparticle action on the plasma and is regulated by changing cloud parameters. The ability to control processes in complex plasma can contribute to increasing stability and reproducibility of its parameters.

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Interaction of particles with inhomogeneous surface properties in a non-uniform electric field

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Today, there is great interest in studying plasmas and environments containing active particles [1–3], including Janus particles [4, 5], so studying the electrostatic interaction of such particles is of interest. Also, while dust particles are in plasma, their surface properties may change, this may also alter the nature of their electrostatic interaction. Another aspect of the electrostatic interaction of microparticles in dusty plasmas under terrestrial conditions is the presence of a non-uniform electric field in the region of microparticle levitation [6], which also leads to a change in the nature of the interaction and to a change in the conditions of microparticle levitation.

This paper examines the electrostatic interaction of spherical Janus particles and the influence of electric field inhomogeneity in the region of microparticle levitation on their interaction. To simplify the problem, an axially symmetric problem is considered. It is shown that the nature of the free charge distribution and the presence of a uniform or non-uniform electric field lead to significant changes in the nature of the electrostatic interaction of the particles.

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Microparticle heating in cryogenic gas-discharge plasma

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The electric discharge with microparticles is an effective tool for creating the necessary concentration of cold ions [1]. Therefore, information about microparticle surface temperature is necessary for the organization of effective ion-plasma reactions involving microparticles at cryogenic temperatures. In this paper, a numerical analysis of the heating of microparticles in neon glow discharge at a temperature of 77 K is carried out [2]. The temperature of microparticles is determined by the balance of heating of its surface by the flow of kinetic energy of ions and electrons, the energy of electron-ion pair recombination, the release of energy during quenching of metastable atoms, and the cooling flow of heat carried away by neutral gas atoms [3, 4]. It was found that the temperature of the microparticles exceeds the temperature of the surrounding gas. The relationship between the surface temperature of a microparticle and its coordination inside the cloud and the concentration of microparticles is revealed. It is shown that the heating of microparticles at the periphery of the cloud can be higher than in the center of the cloud, decreases with increasing concentration of microparticles, and in denser clouds the temperature profile of microparticles evens out.

Investigation of the spin-motion of alone dust particles in plasmas of different inert gases

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This paper presents the results of an experimental study of the rotation of alone glass microspheres in the plasma of inert gases: helium, neon, and argon. Based on an analysis of the obtained data, a physical model is proposed in which the rotation arises from the interaction of an asymmetric ion flow with defects and irregularities on the particle surface. Using the expression derived for the angular velocity in the proposed model, numerical estimates are obtained for the angular velocity of the particle's rotation, depending on the degree of surface imperfection, the radius of the spherical particle, and the plasma parameters. The numerical estimates yield values of approximately 3000 rad/s, which are consistent with experimental data.

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Evaluating the tungsten and carbon impurity fractions in hydrogen plasmas from the Stark broadening of H_β line

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The analysis of spectral line profiles of neutral hydrogen is actively used to diagnose tokamak divertor plasma [1]. In this paper, reduced mass effect [3] is proposed to be used to estimate the concentration of impurities in the materials of the first wall of the tokamak. Using the theory developed in [1], calibration dependences of the intensity in the center of the H_β spectral line on the impurity concentration were obtained and the principal possibility of using the reduced mass effect to estimate the concentration of a homogeneous admixture of tungsten and carbon in the divertor plasma was shown.

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The effect of a magnetic field on dust particle charge

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Applying an external magnetic field is a common method for influencing dusty plasma. Dust structures created in dust traps within glow discharge strata rotate in an external magnetic field. To date, dependences of the angular velocity of dust structure rotation on magnetic field induction up to 2 T have been obtained.

According to probe theory, under current experimental conditions, a decrease in dust particle charge and a change in rotation velocity should be expected. An analysis of the rotation dynamics of dust structures conducted in this study demonstrates that the charge remains constant. Numerical estimates of charge change in a strong magnetic field were made. The obtained data are confirmed by independent experiments in an rf discharge in a field of 6 T.

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Investigation of the possibility of determining the concentration of heavy element impurities in hydrogen plasma by spectroscopic methods

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This work proposes the application of spectroscopic diagnostics for investigating low-temperature hydrogen plasma containing heavy element impurities. The concentration of these impurities is determined through analysis of the H_β spectral line profile. The calculations of the line profiles incorporate the effect of ion thermal motion on Stark broadening [1, 2]. The results have been verified against existing experimental data [3].

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Correlation of microwave emission and current oscillations in the initial stage of a long spark discharge

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We study the correlation between current oscillations and microwave (MW) radiation in the initial phase of a megavolt discharge across an extended (~ 50 cm) air gap. Experiments were performed on a large-scale axial-symmetry installation of the ERG [1]. Current dynamics were measured via an anode shunt, and MW radiation was detected by a broadband Vivaldi antenna [2]. Analysis reveals a consistent ~ 1 ns delay of the MW signal relative to the current pulse, with an additional 3 ns attributable to the signal path geometry. These current oscillations are synchronous with peaks in dU/dt and correlate with key plasma events such as streamer merging [3] or leader connection [4]. The observed delay suggests that MW emission is not a direct bremsstrahlung effect but likely results from the finite-time excitation of plasma oscillations or electromagnetic modes by relativistic electron clusters generated during the current burst. The work was financially supported by the Russian Science Foundation (grant 23-19-00524).

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Anisotropic linear structures of active Brownian particles depending on external parameters in DC discharge

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Active Brownian particles are extremely widespread and can be met in systems of diverse complexity and scale. Active colloidal particles exhibit collective behavior and may self-organize in various types of structures in different environments: liquid, gas and plasma [1]. Dynamic and morphological characteristics of such systems are dependent on external parameters [2].

Presented experimental results of investigation of an anisotropic linear structure of active Brownian particles in dependency on external parameters in DC discharge. The structure formed by 10 polydisperse CeO₂ particles. During the experiment the discharge current was varied from 0.75 mA to 2.5 mA, the pressure of buffer gas was varied from 30 mTorr to 45 mTorr.

According to obtained data were reconstructed the particles' trajectories and calculated its average mean square displacements, kinetic energies, interparticle distance and deviation from axis of a structure. The dependencies on pressure and discharge current were investigated. This research was supported by the Russian Science Foundation (RSF), grant No. 25-12-00406

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Physical installation for generating high-enthalpy gas flows

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The report considers the possibilities of using an experimental installation that was developed at the UPI (UrFU) [1]. It generates heated high-speed gas flows for the study of thermal destruction of materials, including studying the properties of heat-resistant and heat-shielding materials. Studying of the ablation processes and reflow is also possible with the installation. The mechanism of using a high-frequency arc discharge to heat a gas stream is described. The technical characteristics of the installation and the range of parameters obtained in the generated plasma jet are presented. Examples of the installation's use and results obtained in studies of the properties of heat-resistant and heat-shielding materials, as well as in experiments on the ablation of extraterrestrial matter, are shown.

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Evolution of wave processes in the system of synthesized Brownian particles

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Micro- and nano-particles can be formed in the volume of the gas-discharge plasma. By acquiring a significant electrical charge in plasma, the particles exhibit unique dynamic properties, including the ability to self-organise [1]. In such particle's structures, various collective effects are possible, for example the occurrence of dust-acoustic instabilities [2].

Experimentally studied wave processes in the system of synthesized Brownian particles, dispersed in plasma of DC glow discharge. Observed the appearance and development of dust-acoustic instability in the system with its evolution over time. It has been demonstrated that an increase in particle concentration within the cloud leads to substantial modifications in the wave parameters.

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Analysis of spectral line contours in diagnostics of complex plasma

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Experimental study results of complex composition plasma formed during interaction with the wall of laboratory setups are important for applications and materials science. Such setups include the PLM setup developed at MPEI [1], for plasma testing of materials, and the erosive discharge in a capillary, studied at the JIHT RAS [2]. When in direct contact with the plasma, the plasma channel surface or the test sample undergoes intense erosion or structural rearrangement. At the same time, the wall material enters the plasma itself, forming complex emission spectra, whose processing and interpretation are difficult: spectral lines are often superimposed on each other, can differ in intensity by several orders of magnitude, have different “normal temperatures and the radiation can be “locked- [1,2]. In this report we propose methods for taking these features into account and using them for diagnostic purposes.

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A numerical model of shock wave propagation from a powerful high-pressure pulsed discharge in a gas-discharge chamber

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The radial propagation of a shock wave in a cylindrical high-pressure discharge chamber filled with hydrogen has been studied by numerical simulation. The simulation was performed for conditions of a powerful electrical breakdown with a current rise rate of $\approx 10^{11}$ A/s. A system of equations of gas dynamics for a compressible inviscid medium was used for the mathematical description of gas dynamics [1], and a finite-difference scheme was used for the numerical solution, taking into account various models of energy release [2]. Based on comparison with a wide range of experimental data [3], it is shown that the model qualitatively reproduces the key processes: the evolution of the shock wave and the pressure build-up on the chamber wall. The qualitative coincidence of the calculated and experimental curves confirms the applicability of the numerical method used to describe hydrodynamic fields. It is established that the accuracy of the simulation critically depends on the initial gas pressure and the adequacy of the mathematical model of the disturbance source.

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Spectroscopic measurement of a barium loss rate from a hollow cathode emitter depending on its temperature

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Barium depletion in hollow cathodes is one of the key factors limiting their lifetime [1]. The optical emission spectroscopy methods were applied to evaluate a rate of barium loss from the emitter. A method of barium concentration assessment in the emitter's plasma based on the intensity of its spectral lines was proposed. The study involved monitoring of the intensity of the atomic barium line with a wavelength of 553.5 nm. The barium concentration in plasma and, consequently, its loss rate was estimated using the proposed method. The cathode was investigated in two modes: external heating and autonomous mode. It was revealed that external heating increases a barium loss rate by an order of magnitude. Thus, a number of heater activation cycles should be taken into account when predicting a cathode lifetime.

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Computational study of the behavior of the electron distribution function in the discharge channel of a Hall thruster

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This work investigates the electron distribution function in a cathode region of the Hall thruster discharge channel in various magnetic field configurations using a two-dimensional axial-azimuthal electrostatic Particle-in-Cell (2D2V PIC) model. The temporal evolution of the distribution function was analysed, and the contribution of different energy groups to the turbulent current generated by the interaction with azimuthal waves [1] was determined. Two distinct generation mechanisms were identified. They are differentiated by the presence or absence of a dominant energy group of electrons with the Larmor radius, which is smaller than the wavelength of azimuthal instabilities. Periodic modulations in the profile of the velocity distribution function are observed if a dominant group is present, namely the fraction of electrons in a dominant group and the magnitude of turbulent current change synchronously.

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Characterization of spontaneous arcs on fuzzy tungsten surfaces under exposure to helium plasma

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In nuclear fusion devices, plasma-facing tungsten elements are prone to the formation of nanostructured layers due to surface irradiation with intense helium ion fluxes. These so-called W fuzz layers are known to facilitate the initiation of electrical discharges on the first wall. In this contribution, we experimentally investigate the growth of nanostructures on tungsten surfaces in an RF He plasma and the spontaneous initiation of arcs when a pulsed bias voltage is applied to the sample. A custom-built power supply was used to generate the bias in a single-pulse mode. The arc current and voltage waveforms were obtained, and the scanning electron images of the arc traces were analyzed. The behavior of the arc at the smooth/fuzzy surface boundary directly demonstrated the beneficial arcing conditions of the nanostructured layer. Using single-pulse bias mode enabled registration of individual arc traces. From the experimental results, the total arc trace length and arc velocity were calculated and compared with literature data, yielding good agreement between experiments and theory, as well as across different arc initiation conditions. The work was supported by the Russian Science Foundation (grant No. 22-12-00274).

The thermophysical properties of low-temperature germanium plasma

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Various fundamental and applied tasks of physics require the information about thermophysical properties of a substance (the thermodynamical ones and electronic transport coefficients). So these properties have been investigated for more than a century and presently the necessary data is already obtained for many substances at different temperatures T and densities ρ even in the plasma region [1]. Nevertheless, for Ge the appropriate data are still absent in the low-temperature plasma (LTP) region, which is located at $T \leq 5 - 10$ kK and $\rho < \rho_0$ ($\rho_0 = 5.23$ g/cm³ - is the density at ambient conditions). Germanium at ambient conditions is semiconductor. It plays important role in electronics. So there are many investigations of its properties in crystal and liquid phases, which together with relatively low melting temperature $T_m=1211$ K allow to construct reliable equations of states at $\rho \sim \rho_0$ [2]. However the data at lower ρ in LTP are still absent in literature, although they are presented for close element - Si [3, 4]. Previously, to solve this problem for other substances, we have developed a model of calculations of the investigated properties, which are based on the chemical approach and relaxation time approximation, see [4–6] and references therein. In present study we have modified this model and applied it to Ge LTP at 10^{-5} g/cm³ $\leq \rho \leq \rho_0$ and 8 kK $\leq T \leq 100$ kK.

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