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XL Fortov International Conference on Interaction of Intense Energy Fluxes with Matter, March 1-6, 2025

The book includes the abstracts of plenary, oral and poster contributions to the XL Fortov International Conference on Interaction of Intense Energy Fluxes with Matter (March 1–6, 2025, Elbrus, Russia). The reports deal with contemporary investigations in the field of physics of extreme states of matter. The following topics are covered: interaction of intense laser, x-ray and microwave radiation, powerful ion and electron beams with matter; techniques of intense energy fluxes generation; experimental methods of diagnostics of ultrafast processes; shock waves, detonation and combustion physics; equations of state and constitutive equations for matter at high pressures and temperatures; low-temperature plasma physics; physical issues of power engineering and technology projects.

The conference is supported by the Russian Academy of Sciences.

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1. Power Interaction with Matter

Physics of exawatt light fields

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The report discusses the development of a new scientific direction at the intersection of high-energy physics and the physics of extreme light fields. In several countries around the world, large research infrastructures based on multi-petawatt and sub-exawatt laser facilities are being constructed. These facilities enable the focusing of laser pulses with durations of around 10 femtoseconds to achieve gigantic intensities exceeding 10^{23} W/cm^2. The states of matter and vacuum that arise in such fields are currently the subject of theoretical research, predicting remarkable properties and promising unique applications. The report will present opportunities for generating ultra-dense electron-positron plasma and powerful sources of highly directional gamma radiation in the laboratory, for studying the spatiotemporal structure of the quantum vacuum, as well as discuss approaches for further advancing the intensity scale and approaching the Schwinger field level.

Intense hadron beams for research into matter at extremes

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The next generation of heavy ion drivers—NICA, FAIR, HIAF—will provide worldwide unique accelerator and experimental facilities allowing for a large variety of unprecedented fore-front research in extreme state of matter physics, nuclear astrophysics and applied science. This presentation outlines ongoing activities on development of accelerator facilities, providing high-brightness beams capable of generating intense beams in conventional and collider modes as well. Manifested facilities goals are pushing the "intensity" and the "precision frontiers" to the extremes when accelerating full range of ion beam species from p^+ to U, electron-positron colliders to highest beam intensities and luminosities.
Overview of the rapid progress in development of heavy ion accelerator facilities worldwide and in JINR is presented. Dubna accelerators are capable of generating high-brightness intense beams of heavy ions and protons for basic research and for various applications. Construction of new generation of heavy ion accelerator facilities is progressing well and forefront accelerator technologies are under development for low energy as well as for relativistic heavy ion and proton beams.

Photonics and optoacoustics (the 1st part) and action of x-ray lasers (the 2nd part)

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1. Applications in telecommunications and nanosensing. Structured optically thick films are considered in the report. Due to their special structure, these films transmit light [1]. Although the film thickness is optically large: it is 5-7 skin layer thickness. At the same time, the film remains an effective transducer of terahertz sound generators in the film and substrate [1]. Thus our device combines the properties of photonic and optoacoustic devices. The films are created by magnetron sputtering inside few Pa Argon atmosphere.
2. Applications in material processing. A comparative analysis of ablation by femtosecond high intensity soft ($I \sim 10^{15}$ W/cm^2) 92 eV and hard ($I \sim 10^{18}$ W/cm^2) 9 keV X-ray [2] lasers has been performed. Modern XFEL produce X-ray beams with low divergence. To increase the intensity, the beam is focused into the smallest possible spot. In our work, the minimum size for soft X-rays is 3 um and 0.4 um for hard X-rays. The difference is that the attenuation length is very different for soft (few tens of nm) and hard X-rays ($\sim$ 1 mm for light elements, 7 mm in Be). This fact leads to a qualitative difference in the nature of the induced flows. In the hard X-ray case mm long empty cavity is formed not by ablation but due to radial indentation of matter along cavity.

[1] Petrov Y V, Romashevskiy S A, Dyshlyuk A V *et al.* 2025 *Zh. Eksp. Theor. Fiz.* **167**(4)
[2] Makarov S, Grigoryev S Y, Zhakhovsky V V *et al.* 2024 *arXiv:2409.03625 [physics.plasm-ph]*

Laser painting—first steps

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Laser technologies are increasingly penetrating into modern artistic creativity. If at first it was artistic cutting and engraving, then laser cleaning of works of sculpture and art, now the first steps in laser painting have been taken—methods and tools have been developed for creating full-color laser miniatures. One such method, local laser oxidation of metals, allows the creation of spatially controlled oxides of interference thickness on the surface, which determine the image. The developed hand tool—a laser "brush"—in the artist's hand will allow you to draw plot and ornamental compositions in an original way. The talk discusses the physical principles of this laser "painting", showing laser brush designs and artistic images created using this new technique.

Estimation of biological protection parameters of electron-beam vacuum furnace

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The All-Russia Electrotechnical Institute (VEI, the RFNC-VNIITF branch) has developed electron-beam vacuum furnaces for ultra-clean metal remelting, including refractory metals such as tungsten, niobium, and molybdenum. In these facilities an electron beam with energy of more than 10 keV is used to heat an object by energy release of electrons directly within the heated object bypassing crucibles and other devices. Such approach ensures a number of advantages such as the absence of contamination and metal oxidation in vacuum, ease of control and process automation, and a wide range of effects on the object being processed. However, the interaction of electron beam with such energies is accompanied by the release of x-rays from the irradiated material, which imposes additional requirements to the facility operation, i.e., the use of x-ray protective shields is required.

In accordance with radiation safety standards NRB-99, radiation safety justification is required when preparing design documentation for such facilities. It is necessary to use the first class of standards containing the values of the basic dose limits for man-made radiation under controlled conditions excluding doses from natural and medical sources.

In the present work, the PRIZMA code is used to estimate the x-ray radiation yield from a tungsten target imitating a smelted ingot. Also this code is used to estimate the attenuation of x-ray radiation in different materials depending on their thickness.

Control of ablation pressure during direct irradiation of low-density targets with laser pulse

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The results of experiments on increasing the ablation pressure under direct laser irradiation of two-layer targets with low-density ablator are proposed. A series of experiments were conducted at the MIK stand. To irradiate targets, 0.527 μm long radiation from 8 laser channels with an energy of $\approx$ 4 kJ each was used, the pulses had a trapezoidal shape with half-height duration of $\approx$ 4.3 ns. The irradiation spot was $\approx$ 900 μm for the experiments given, according to the pinhole readings. The two-layer targets were made of low-density a carbon-used ablator with density of 44 mg/cc and step indicator made of copper. The ablator was placed in fluoroplastic cylinder 800 μm long and 1 mm in diameter, which prevented lateral unloading of material. The shock wave velocity was measured using a photochronographic technique in copper step indicator with a base thickness of 40 μm and two steps of 20 μm. The maximum velocity in the indicator was 34.2 km/s. which corresponds to a pressure of 77 Mbar. The obtained results are in good agreement with one-dimensional calculations. The study was carried out within the framework on the scientific program of the National Center for Physics and Mathematics (project "High Energy Density Physics. Stage 2023–2025").

Oscillations of a metal film on a substrate under the action of USLP with intensity under the melting threshold

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The effect of UCLI on metal films was investigated. Due to the fact that the repetition rate of heating pulses was reduced, it was possible to reach temperatures near the melting point while using the accumulation of a useful signal on the background noise [1, 2]. Nonlinear effects and the effects of $2T$ on the post-$2T$-stage are observed. Our experiments with Au showed that in the range of fluences with peak temperatures Te above 10 kK and up to 20 kK, the measured values of α and κ are significantly lower than those values, that the theories give. Below this range of fluences, i.e., when the peak T_{e} is less than 10 kK, our measured values are in agreement with previous data. In addition, it is shown that at a one-temperature stage, when in our conditions the thermal energy stored in the electrons is very small, there is a significant influence of the fundamentally two-temperature coefficient $alpha$ on the heat transfer from the skin layer.

[1] Khokhlov V A, Romashevskiy S A, Ashitkov S I and Inogamov N A *JETP Letters* **120** 531–539 URL `https://link.springer.com/article/10.1134/S0021364024603208`

[2] Inogamov N A, Khokhlova V A, Romashevskiy S A, andM A Ovchinnikov Y V P and Ashitkov S I *JETP* **165** 165–190

Weibel instability in the laser plasma induced by ultrashort 250 TW laser pulse

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The Weibel instability is ubiquitous in nature, occurring in coronal ejections of stars [1], in the solar wind, as well as in laser ablation and plasma heating by powerful ultrashort laser pulses, for example, in Fast Ignition (FI) experiments. Weibel instability occurs in plasma with an anisotropic distribution function or in interpenetrating particle flows. Small-scale static magnetic fields are generated as a result of current filamentation and can reach the Megagauss level. The present work reports the results of experimental investigations of the Weibel instability in a plasma produced by irradiating a target by the 250-TW laser pulse from the PEARL laser facility. The peak intensity of the laser pulse reached 2×10^{18} $\frac{W}{cm^2}$. The small-scale electrical current instability was investigated using optical refractive, interferometery and Faraday rotation methods [2].

The study was supported by a grant from the Russian Science Foundation No. 24-62-00032.

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[2] Swadling G, Lebedev S, Hall G, Patankar S, Stewart N, Smith R, Harvey-Thompson A, Burdiak G, De Grouchy P, Skidmore J *et al.* 2014 *Review of Scientific Instruments* **85**

Plasmon localization, giant electromagnetic field, and surface-enhanced Raman spectroscopy in flexible metasurfaces

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We explore the optical properties of plasmon localization and local field enhancement in metal-plastic metasurface. The flexible metal-dielectric metasurfaces are made from modulated polycarbonate substrate coated by silver nanofilm [1]. Localization of an optical excitation is experimentally observed by near-field scanning optical microscopy within subwavelength areas in the regular open-resonator metasurface. The localized modes are seen as giant fluctuations of the local electric field spatially concentrated in hotspots, where the local field is much larger than the amplitude of the incident light. Local near-field spatial spectra consist of regularly distributed strong peaks. The maxima of the electric field are highly dependent on the sample structure. The form of the regularly distributed strong resonance peaks follows the topography obtained by atomic force microscopy. It is shown that strong electromagnetic field is concentrated in recesses where the silver film is typically thinner than on the bumps. This experimental observation is consistent with the results of computer simulations of a double-periodic metal-dielectric metasurface and the predictions of our analytical theory. It is found the silver nanofilm has strong adhesion to polycarbonate substrate. The metasurface is used as an effective SERS substrate.

[1] Ivanov A, Bykov I, Barbillon G, Mochalov K, Korzhov D, Kovalev A, Smyk A, Shurygin A and Sarychev A K 2024 *Phys. Rev. Appl.* **22**(6) 064064

Nuclear photonics with table top femtosecond laser

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Nuclear photonics is one of new rapidly developing areas of scientific research at the intersection of nuclear and atomic physics as well as accelerator and laser physics [1]. Most frequently large-scale linear accelerators or rings are used, while large PW lasers with plasma based accelerators came into play last decade. At the same time modern table top femtosecond lasers deliver enough peak power and intensity at a much higher repetition rate, thus enabling a much higher average current. Energies of accelerated electrons amount to 10-100 MeV thus being enough for a wide variety of nuclear processes including photonuclear reactions, etc.
This paper presents our recent experimental results on photonuclear reactions with different targets using table top 2 TW 50 fs 10 Hz laser. We produce well collimated electron bunches with electron energies up to 20 MeV, bunch charge 0.1-1 nC [2]. Different diagnostics were used to detect the full neutron yield and the neutron's spectra.

[1] Nedorezov V G, Rykovanov S G and Savelev A B 2021 *Physics Uspekhi* **64**(12) 1214–1237

[2] Ivanov K A, Tsymbalov I N, Gorlova D A, Shulyapov S A, Starodubtseva E M, Zavorotnyi A Y, Samsonov A V, Pavlov A I, Volkov R V and Savel'ev A B 2024 *Bulletin of the Lebedev Physics Institute* **54**(5) 312 – 324

Experiments of S.E. Shnol and N.A. Kozyrev. Physical nature of the long-range action of Newton's gravity

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The results of experiments by S.E. Shnol [1] and N.A. Kozyrev [2], who discovered the discrete influence of the Sun, Moon, individual planets and a number of stars on the near-Earth gravitational field, are discussed. These experiments make it possible to establish the physical nature of the long-range action of Newtonian gravitation. It has been shown [3] that the carriers of the gravitational force are gravitons, which are massless virtual vector bosons that transfer the energy of gravity to bodies directly on the spot. The energy of virtual gravitons is $\sim 10^{-5} - 10^{-4}$ eV. The gravitational field is adequately described by a tensor in a vector space, the dimension of which is determined by the number of bodies creating this field at each point in space according to Newton's law of gravitation. At the same time, in many practically important cases, it is possible to limit ourselves to taking into account only the bodies of interest to us. The established mechanism of gravity is applied to the interactions of light photons with gravitational fields in space. In this case, it explains [4] the Hubble redshift law, the temperature of the cosmic microwave background, and the energy spectrum of virtual gravitons.

[1] Shnol S E 2009 *Cosmophysical Factors in Random Processes* (Stockholm: Svenska fysikarkivet)

[2] Kozyrev N A 1991 *Selected Works* (Leningrad: Leningrad University)

[3] Barenbaum A A 2024 *Proceedings of VESEMPG-2024* (Moscow: Vernadsky Institute of the Russian Academy of Sciences) pp 221–226

[4] Barenbaum A A 2021 Hubble's law and the cosmic microwave background in the absence of the big bang *Research Trends and Challenges in Physical Science* vol 4 pp 119–130

Response of solid dielectrics to combined electrical and mechanical pulse critical action

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A criterion based on the Landau potential is proposed to describe the experimental data on the fracture of materials under pulse impact. The introduction of a parameter characterizing the time interval necessary for the beginning of the destruction process, i.e., the time of energy accumulation at constant entropy, showed the generality of the destruction process. In a wide range of exposure durations (rise time from ps to microsec), a dependence describing the increase in mechanical strength with decreasing exposure time was obtained, with the energy accumulation time being a material characteristic. A similar dependence was obtained for the electrical pulse strength of some dielectrics. It is revealed that the relative power required for fracture or breakdown depends only on the ratio of the duration of exposure to the time of accumulation of the corresponding energy. The possibility of using the proposed criterion to determine the threshold pulse loading in conditions of combined pulse mechanical and electrical effects is shown.

High-power laser filamentation dynamics in high-pressure nitrogen

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Modern trends in atmospheric-optical research are closely related to nonlinear femtosecond laser physics. Their practical focus is remote atmospheric diagnostics, efficient energy delivery over long paths, plasma formation. The main prospects in these cases are associated with the phenomena of self-focusing [1] and filamentation [2] of high-power laser pulses. In particular, in recent years [3], [4], pulses propagation have been actively developed. The interest is also related to the possibilities of scaling the results obtained in laboratory conditions to the real long-range atmospheric paths [5].
In this work, the influence of the gas pressure in the optical cuvette on the characteristics of the titanium-sapphire laser radiation propagating in the self-focusing and filamentation mode was experimentally and theoretically studied. The cuvette gas under the pressure of 1 to 11 atmospheres was nitrogen. In general, with increasing gas pressure in the optical cuvette, the average diameter of postfilaments decreases, and their number increases (with a tendency to saturation).
This study is supported by the Russian Science Foundation (Agreement No 24-12-00056).

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[4] Li S, Yu M, Cai X, Zhang H, Jin M and Wu J 2023 *Optoelectron. Lett.* **19**(10) 605–613
[5] Geints Y E 2024 *Optics Communications* **573** 131007–1–131007–8

High-speed imaging system with a laser monitor for studying high-temperature combustion processes

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Self-propagating high-temperature synthesis and plasma synthesis are promising methods for obtaining new materials with specified properties. The properties of the products are determined not only by the composition of the components, but also by the dynamics of the processes. No less popular direction in the study of extreme states of matter is high-temperature combustion. An urgent task is a comprehensive study of the thermal effects of the high-energy substances on infrastructure objects to ensure technospheric safety. Imaging systems based on high-speed cameras and laser radiation allow monitoring through bright illumination accompanying the flow of high-temperature processes [1], [2]. The report discusses the laboratory complex for high-speed visualization based on two high-speed cameras Evercam F 1000-16-C (Russia) and an original copper bromide brightness amplifier. The complex was used to visualize contact and laser initiation and high-temperature combustion of thermite mixtures, and electric arc synthesis of refractory materials at atmospheric pressure. Using proposed experimental technique, it is possible to understand the features of the processes during combustion of the thermite mixture or processes in the crucible during plasma synthesis. This will make it possible to use the obtained results in solving current problems in the field of combustion physics and other extreme states of matter.

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[2] Gubarev F A M A V and L L 2023 *Opt. Laser Technol.* **159** 108981

Ultrafast non-linear hybrid mid-IR laser photoionization and micromarking of immersed diamond

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Direct interband and intragap photoexcitation by intense mid-infrared (MIR, 4.0 and 4.7 microns) femtosecond (fs) laser pulses was explored in ultrapure chemical-vapor deposited (CVD) diamond via acquisition of characteristic UV photoluminescence (PL) of free excitons and A-band PL of electrons anchored at deep donor-acceptor or dislocation-related traps, respectively. At lower laser intensities (¡ 10 TW/cm2) the excitonic PL yields exhibit highly non-linear dependences with (intensity x lambda2)-scaling and power slopes N=17 (4.0 microns) and 14 (4.7 microns), still insufficient to cross over the direct bandgap (6.5 eV) by 1.2 and 2.8 eV, respectively. Similarly high slope of 9 (4.7 microns for intragap (3.5 eV) photo-population of donor-acceptor traps is still insufficient for their direct excitation by 1 eV. At the intermediate (intensity x lambda2)-dependent values of the Keldysh parameter "gamma" about 1 such incomplete multi-photon excitation anticipates the hybrid total "multiphoton+tunneling" photoexcitation generally predicted by the Keldysh theory, but never unambiguously experimentally demonstrated. At higher laser intensities (¿ 10 TW/cm2) both the excitonic and A-band PL yields exhibit (sub)linear slopes, apparently, indicating formation of more strongly absorbing electron-hole plasma. These findings shed light on the hybrid "multiphoton+tunneling" character of Keldysh photoexcitation at intermediate values "gamma" and pave the way to defect/impurity band engineering of intragap non-linear optical properties in bulk dielectrics for their precise fs-laser nanomodification through IR-transparent low-melting solid-phase immersion.

Tunable quasi-monoenergetic LWFA electron beam

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Laser plasma acceleration of charged particles represents one of the most promising applications of ultraintense lasers. One of the most promising laser plasma acceleration mechanisms is laser wakefield acceleration (LWFA). This mechanism can be implemented to generate electron beams with energies in the range of tens MeV that are valuable for a variety of applications, such as investigation of the photonuclear reactions near threshold.

We have demonstrated the generation of energy-tunable quasi-monoenergetic electron beams by interrupting the acceleration process at different stages by introducing a sharp density spike created by a laser-induced blast wave [1]. Electron beams with tunable energies ranging from 6 to 12 MeV and an energy spread of 2 to 3 MeV were achieved by this approach experimentally. Energy tuning occurs during the deceleration phase. The spectrum is quasi-monoenergetic in a tuning range. Additionally, we conducted an extensive analysis of the 1D quasi-linear model of LWFA to elucidate this effect [2]. The analytical model provides a theoretical framework for understanding the generation of quasi-monochromatic energy-tunable electron beams through LWFA and offers accurate estimates of the electron beam parameters.

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[2] Starodubtseva E, Tsymbalov I, Gorlova D, Ivanov K and Savelev A 2024 *Laser Physics Letters* **21** 075401

Heat transfer in pulsed superheated solutions with a lower critical solution temperature: experiment and model

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Local superheating and transition of the liquid coolant to a not quite stable and/or unstable state occurs during operation of microelectronic devices in confined spaces and high heat flux density. In the on and control modes, overheating occurs relative to the liquid-vapor equilibrium line or, for solutions with a lower critical solution temperature (LCST), the liquid-liquid equilibrium line. A new promising class of coolants for cooling microprocessors are solutions with LCST, for example, aqueous solutions of polypropylene glycols (PPG). The authors obtained and compared a significant array of heat transfer data for aqueous solutions of PPG-425, PPG-725 and PPG-2000. The method of controlled pulsed heating of a platinum probe (20 μm) was used to simulate local isothermal conditions in the samples. Significant asymmetry and a significant increase in heat transfer of the solution compared to pure liquid were found at low concentrations and concentrations below the critical one LCST. At significant concentrations of PPG, the effect practically disappears. A model of the kinetics of spinodal decomposition of solutions with LCST is constructed, explaining the asymmetry of heat transfer found in the experiments. It is shown that the presence of non-Newtonian properties in PPG explains the significant asymmetry of decomposition in the pulse experiment. The dependences of power on time during pulse heating of the probe at a constant temperature are obtained. These dependences qualitatively coincide with the experimental ones. 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

Measuring the parameters of relativistic electron beams accelerated from thin solid targets by femtosecond laser pulses of 100 TW power

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A series of experiments on the generation of relativistic electron beams from thin solid targets was carried out using a femtosecond high-intensity laser system. Metal (W, Ta, Al) foils with a thickness of 15÷500 μm, as well as Mylar of 175 μm thickness were used as targets in experiments. Spectra, angular distributions and total charges of the relativistic electron bunches accelerated in the laser field and transmitted to the back side of the target were characterized.

All measured relativistic electrons spectra follow the relativistic Maxwell distribution $dN_e/dE = A \times E^2 \times \exp(-E/T)$, where A is a constant, T is the characteristic temperature of the distribution which in experiments was in the range from 1 to 3 MeV. The maximum electron energy in experiments was about ∼40 MeV. The divergence angle (FWHM) of electron beams was about 20°÷45° and the total beam charges of tens of nC/pulse were obtained.

Regularities and mechanisms of copper surface relief formation under pulsed laser action

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An experimental study and molecular dynamic (MD) modeling of the formation of surface relief (known as the optoplastic effect) and the microstructure of thin near-surface layers of copper after exposure to laser pulses of nanosecond duration with parameters corresponding to the absence of ablation have been carried out. The determining role of thermoplasticity, realized by the formation of deformation twins in the form of nanoscale plates, as well as dislocation walls of slip systems $\{111\}\langle 110\rangle$ and $\{111\}\langle 110\rangle$ common for the FCC lattice of copper, is established. The results of MD modeling are confirmed by experimental data, which allows validating the model for the processes in materials under laser exposure under the specified conditions.

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Application of photonic crystals for microwave generation with high energy accelerator beams

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In this work, the generation of electromagnetic radiation of a wide spectrum, including microwave and sub-terahertz ranges using three-dimensional ordered nanostructures such as photonic crystals were measured. Generation occurred when the exciting electron beam, created by linear accelerator LINAC-200, passed along the planes of orientation of the globules of the photonic crystal. By varying the orientation of the photonic crystal relative to the electron beam and the beam energy, a tunable narrowband microwave and terahertz source was created. Our experiments involved a set of photonic crystals with different globule diameters and elemental compositions and also included comparative studies using samples of dielectric and semiconductor monocrystals and powders with monodisperse globule sizes. We found that that electromagnetic radiation from single crystals has a similar frequency structure to that of a photonic crystal in the form of a set of narrow-band peaks with a width at half maximum of several MHz appearing in the case, when the beam is passing along the crystallographic orientation axis of the single crystal.

Simple numerical method for studying UV radiation with orbital angular momentum through laser plasma interaction

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Recent advancements in laser physics and nonlinear optics are enhancing our understanding of high-intensity laser pulse interactions with materials. High-order harmonic generation (HOHG) [1], which occurs when a powerful laser pulse interacts with plasma, produces ultraviolet (UV) radiation with unique properties such as orbital angular momentum (OAM) [2].

This article focuses on modeling such a phenomenon. One process involved in HOHG is the relativistic oscillating mirror (ROM) [3], where a laser pulse interacts with the overdense plasma, creating an oscillating mirror that reflects the pulse. The conventional approach uses a computationally demanded solution for the Vlasov-Maxwell equations. However, Einstein's 1905 model [3] of relativistic mirror motion offers a simpler, more computationally efficient alternative, suitable for qualitative studies.

For simulations, we use Laguerre-Gaussian modes for laser, and the target is treated as a relativistically moving mirror with perfect reflection. This paper introduces a lightweight 3D numerical tool for modeling HOHG from overdense plasma and generating harmonics with OAM, including fractional and dynamic OAM.

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Surface cleaning by a linear electrodynamic trap field

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It is possible to capture and retain dust, including dust from surfaces, using an electrodynamic trap. This effect can be applied for cleaning surfaces. Such a method is important for practical purposes for cleaning the inner surfaces of closed dielectric vessels or vessels with limited possibilities of penetration inside. The purpose of this work is to investigate the possibility of cleaning dielectric surfaces from the opposite side of the plate.
A quadrupole linear trap was used with four dynamic electrodes, each 4 mm in diameter and 19 cm long, which were placed at the corners of a square with a side of 2 cm. A glass plate with aluminum oxide powder was placed above the trap, with a bottom plate without particles near the trap electrodes. After applying a harmonic voltage with a frequency of 50 Hz to the trap electrodes on the opposite side of the glass plate, dusting of the surface began. The solar panel surfaces could be cleaned in this way from the side closest to the trap. Thus, the possibility of cleaning dielectric surfaces from dust has been experimentally demonstrated, not only from the plate surface closest to the trap, but also from the bottom surface of the plate. The possibility of removing dust from the surface of a small-sized solar panel from the near side to the trap has been demonstrated.

Production and magnetic self-confinement of electron-positron plasma by an extremely intense laser pulse incident on a structured solid target

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An all-optical scheme for producing dense relativistic magnetized electron-positron plasmas is proposed [1]. The scheme involves interaction of an extremely intense ($I \gtrsim 10^{23}$ W/cm^{-2}) circularly polarized laser pulse with a solid target with a conical cavity. The proposed scheme solves three crucial problems of creating pair plasma simultaneously. For producing high-energy seed particles a target with a conical cavity is used, from surface of which the laser efficiently accelerates electrons [2]. "Conversion" of seed particles into a pair plasma with peak density exceeding 10^{24} cm^{-3} occurs in a standing wave-like structure formed due to reflection of the laser pulse from the tip of the cavity. The created pair plasma is confined for hundreds of femtosecond in quasi-static magnetic fields generated during the interaction due to the inverse Faraday effect [3]. Thus, the proposed scheme can be considered as a universal tool for studying the properties of electron-positron plasma in a wide range of parameters, including those relevant for laboratory modeling of exotic astrophysical environments.

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Four channel low power coherent beam combining set-up in the frame of the XCELS project

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Our work presents a four-channel prototype of a system for geometric convergence and coherent combining of tightly focused femtosecond laser beams in counter propagating geometry. During the interference of the individual laser channels in the main focus of the system occurs a standing laser field configuration close in its structure to the dipole focusing underlying the design of the exawatt XCELS project [1]. The prototype uses radiation from a pulsed femtosecond laser source operating at a repetition rate of about 80 MHz without additional amplification inside the laser chain. The two-stage system for stabilizing the laser radiation direction at the input of the prototype set-up, as well as the phase stabilizing system for four beams were developed and tested.

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Laser acceleration of relativistic electrons in air

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During supersonic expansion of compressed gases a gas-cluster medium is formed, in which, when irradiated with a laser pulse of relativistic intensity, a beam of electrons can be formed. From a thermodynamic analysis, conditions for creating clusters of optimal size were found. Radiation from a multi-terawatt TiSa laser with an intensity of up to $10^{18} - 10^{19} W/cm^2$ and a duration of 30 fs was used [2]. The cluster sizes varied from 3-5 to 50-70 nm, changing gases (N_2, O_2, Ar, Kr, CO_2) and pressures. Effective acceleration of electrons was obtained in nitrogen and oxygen clusters. Their 80/20 mixture and even compressed atmospheric air also are suitable for obtaining narrow, electron beam at plasma concentrations of $n_e \sim 2 - 5 \times 10^{19} cm^{-3}$. The best divergence (8 mrad) with sufficient charge (up to 50 pC) was obtained in gases with the lowest atomic number, with the smallest cluster size (in nitrogen, oxygen and air). Electron beam properties are consistent with a bubble or SM-LWFA acceleration regime [2]. At high pressure (and always in heavy gases), a high electron beam divergence is observed (100-200 mrad), this is consistent with the DLA mode. In optimal gases, a large (3 nC) charge is achieved. The spectrum in all cases is exponentially decreasing, with energy of 1-4 MeV. The results are relevant for obtaining betatron X-ray, bremsstrahlung gamma radiation and intense THz pulses from an electron bunch with a large charge and short duration.

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Microwave induced composite droplet puffing/microexplosion

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The paper presents experimental and theoretical results of microwave induced composite droplet puffing/microexplosion characteristics. The experimental studies were carried out in a microwave waveguide. Theoretical estimates were made using the Comsol Multiphysics software package. Water, kerosene, and rapeseed oil were used as the liquids under study. The results were obtained by varying microwave heating power, ratio and mutual arrangement of the components of the composite droplets, and the type of components. The mathematical processing of the experimental results and numerical modeling was performed in order to obtain approximation expressions for the established dependencies of the puffing/microexplosion characteristics of immiscible liquid droplets under microwave heating. A satisfactory correlation between the experimental and modeling results was obtained.
The investigation was conducted at the expense of a grant from the Russian Science Foundation (project No. 24-79-10031).

High energy particles and X-rays in relativistic laser-matter interaction

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Intense beams of photons and particles in the MeV energy range are effective tools in different areas of research, such as the creation and diagnostics of matter in extreme states, nuclear physics and in other applications. An efficient concept for creating sources of γ-radiation, positrons and neutrons based on the generation of relativistic electrons in the regime of direct laser acceleration is discussed. PW-class laser systems capable of generating subpicosecond and femtosecond pulses focused to ultrarelativistic intensity, are good candidates for creating high-current beams of ultrarelativistic electrons in an extended plasma with a density close to critical [1, 2], which was confirmed in experiments [3, 4].

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Long-wavelength spectral shift in ultraviolet filament

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In experiments on ultraviolet (UV) filamentation, a long-wavelength shift of the spectrum as a whole to the long-wavelength range by several nanometers was observed [1]. This long-wavelength spectral shift was experimentally reproduced in the wide range of pulse durations 450 fs–5 ps and energies 2–7.5 mJ. The numerical simulations [1] demonstrated the symmetrical spectral broadening and did not reproduce its long-wavelength shift. We conducted an experiment in which the pulses centered at $\sim$250 nm with a duration of $\sim$100 fs and energy up to 0.2 mJ were focused into the cell with gas (air or argon) of various pressures. Independently of gas in the cuvette, the increase in pressure results in the monotonic shift of the UV pulse spectrum as whole towards the long wavelengths. To calculate of the nonlinear response of a gas medium on an ultrashort laser pulse we numerically solve time-dependent Schrödinger equation with one-dimentional potential well with bound states, corresponding to energy levels of gas used in experiment and laser pulses of 10–80 fs, a central wavelength of 250 nm in a wide range of intensities. Nonlinear polarization obtained from our simulations delays on the intraperiod timescale relative to the cube of the pump electric field and induces the long-wavelength spectral shift.

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Comparison of electron acceleration efficiency with a powerful laser pulse propagating in a self-trapping mode for two regimes laser bullet and bubble

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The most effective mechanism for laser acceleration of electrons is the relativistic self-capture of a powerful light pulse, which allows one to achieve the limiting values of the laser energy conversion coefficient, can be implemented in characteristic regimes called "laser bullet" and "bubble". Since estimates show that the total energies of electrons accelerated in these modes are comparable in order of magnitude, a quantitative comparison requires 3D PIC numerical simulations. Such sumulation was carried out for relativistically intense ultrashort (6-20 fs) laser pulses of Joule energy level. With regard to radiation-nuclear applications, the results obtained indicate a higher yield of high-energy electrons accelerated in the laser bullet regime, with the exception of extremely short pulse durations, $\lesssim 10\,\mathrm{fs}$, for which both modes provide approximately the same yield of high-energy electrons (over $30\,\mathrm{MeV}$).

Effective sources of gamma radiation under the action of relativistic electrons on combined target

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Bright X-ray and gamma-ray sources are needed in modern physical applications like radiography of ultrafast process in warm dens matter under action of intense energy fluxes, laboratory astrophysics, generation of photonuclear reactions and neutron beams.

We study the possible optimization of the yield N_{ph} of high energy bremstruhlang photons emitted while a bunch of electrons accelerated by powerful PW or sub-PW laser pulses in plasma of near-critical density (NCD) [1, 2] and passed through metallic rear part of combined target. The NCD plasma is created by action of ionizing nanosecond prepulse on the front part of the combined target consisting of aerogel (CHO) foam. The optimization consist of 2 parts: i) maximizing the charge $Q_{>E_n}$ of accelerated electron bunches for group of electrons with energies $E > E_n$ (E_n in MeV) using respective choice of parameters of powerfull laser pulses and plasma created in the aerogel foam. We show the possibility of achieving $Q_{>10} \simeq 1 \div 10^2$ mkCl. ii) maximizing N_{ph} in the considered range of quantum energies E_{ph} (we consider quants with 100 keV $< E_{ph} <$ 10 MeV) for given flux of high energy ($E \sim 1 \div 10^2$MeV) electrons using respective choice of parameters of metallic targets.

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Loretz-invariant diagram for strong field effects at high energies in oriented crystals and laser fields

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We demonstrate that electromagnetic strong field effects at high energies in oriented crystals (OC) [1] and in the field of powerful lasers [2] can be described by the same formulars depending on two Lorentz-invariant parameters. The corresponding calculations of the radiation spectra are presented. The crucial difference between lasers and crystals is that in the former case both invariants are independent, while in the crystal they are linearly related to each other [3]. This leads to a strong limitation on the range of possible values of these invariants in OC.

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Hydrodynamics modeling of the generation of extended homogeneous layers from plate and a layered target

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It is known that in an expansion wave, isentropic kink at the boiling point leads to the formation of a homogeneous, extended region of matter with constant kinematic and thermodynamic parameters ("plateau"). It was previously emphasized ([1]) that the thermodynamic state of matter in the "plateau" zone exactly corresponds to the boundary of the two-phase region, both on the side of the boiling liquid and on the side of saturated steam, including the area of the critical point. It was recommended to use the term "Binodal layer (BL)" as part of the thermodynamic analysis of the "Plateau" phenomenon, and the term "Phase Freeze" for the entire complex of processes associated with BL generation.

The purpose of this work is to search within the framework of hydrodynamic modeling for the possibility of generating homogeneous, extended, thermodynamically equilibrium zones with parameters within the boundaries of the two-phase region of the model substance, with adiabatic expansion of an isochorically heated assembly of periodically arranged plates. By selecting the energy level and the ratio of the plate thickness and the gap between the plates, a solution was obtained in which the entire target substance, after pressure equalization, is in a two-phase region at zero mass velocity and constant sufficiently high temperature.

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Spatio-temporal coupling under tight focusing an ultrashort laser pulse by an off-axis parabolic mirror

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We propose a model in the form of Stratton-Chu integrals to describe ultrashort tightly focused laser pulses. Based on it, we analyze the formation of spatio-temporal coupling and the impact of an off-axis angle of the focusing mirror on the laser pulse dynamics. We show that in the case of the factorizability of the spatial-temporal profile of an incident laser pulse, the computational complexity of the model is equal to one of the monochromatic approximation. The model quality is checked in PIC-simulations by the comparison of results obtained by different approaches.

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Heat transfer coefficient of pulsed superheated aqueous solution of boric acid for efficient and safe operation of pressurized water reactors

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An important independent control and protection system (CPS) of pressurized water reactors (PWR) is the boron control system (BCS). The BCS is designed to compensate for a portion of the excess reactivity at the beginning of a fresh fuel loading campaign and to compensate for slow changes in reactivity during a campaign. Boric acid (BA) is used in the PWR CPS. BA in the primary coolant is used as an absorber of thermal neutrons, and its concentration depends on the state of the core and is set depending on the reactivity margin of the core. Maintaining the PWR in a critical state during slow transient processes is achieved by regulating the concentration of BA introduced into the coolant. The BA concentration is changed either by diluting the reactor coolant with clean water, or, conversely, by feeding the primary coolant loop with a high-concentration BA solution. The range of BA concentration variation is 0 — 16 g/kg. Heat transfer to aqueous solutions of boric acid in the region of stable and relatively stable states is investigated in the case of short-term superheating relative to the solution liquid-vapor equilibrium temperature at different pressures. The heat transfer coefficient of aqueous solution of boric acid was measured by the method of controlled pulse superheating of the wire probe in the temperature range up to 600 K and pressures up to 20 MPa.

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Experimental determination of the titan alloy laser ablation threshold energy density

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The threshold values of the energy density of titanium alloy samples were measured at the Laser ablation station from [1–4] at given incident laser pulse energy values and focusing conditions (dimensional effect) during the destruction of titanium alloy samples. YAG:Nd laser radiation with pulses of 1.6 ms duration and energies up to 1.2 J at the 1064 nm wavelength was used, which was focused with a lens on the titanium alloy sample surface. These experimentally measured threshold values of energy density at probability 0 will be threshold values $F_t = 5.1$ kJ/cm^2 according to GOST [5], and at probability 0.5 – $F_{0.5} = 57.8$ kJ/cm^2 can be used to construct reliability dynamics curves as before in [1, 2]. The probability the value of 1 at a threshold the energy density value $F = 93.5$ and remains so until a maximum value of 170 kJ/cm^2 . These data are physical constants for samples of such a titanium alloy and are in satisfactory agreement with the data [6] .

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Hydrodynamic effects in influence on sodium chloride ultrashort laser pulses

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The character of thermomechanical ablation of NaCl by laser pulses of the order of 40 fs was studied in [1]. In this experiment, according to our calculation, elapse the heating of NaCl to temperature order of magnitude 3 kK [2], which considerable greater boiling-point medium 1738 K [3]. Hydrodynamic phenomena in influence fs laser pulses on the surface of Ag and Au was studied in [4]. It was noted, that in this materials the crater dimension 100 nm has formed with register of the appearance chopping dome, which has begun to separate after the start of nucleation steam embryos into melt metal. This effects must take place for experiments [1] too. The melt of NaCl arise after end laser pulse, and crater dimension order of magnitude 1 μm has formed [1]. Elastic unloading heat layer NaCl thickness 1 μm has elapsed, according to our calculations (if take into account [3]), for 250 ps approximately. Melt NaCl must harden for 2–5 ns approximately. Melt phase NaCl observed with confidence in experiments with laser pulse 80 fs (and with surface density of energy $\simeq 1$ J/sm^2), later 0.5 ns after pulse [2]. Because take place difference of coefficients of heart conduction for NaCl [3], for Ag and Au, become more clearly, that the depth of crater for NaCl by far greater, than the depth of crater for metals.

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Numerical simulation of laser pulse amplification in four-level medium by using Maxwell-Bloch equations

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Typically, a system of balance equations is used to describe the operation of solid-state laser pulse amplifiers [1].However, under conditions of inhomogeneous lasing line broadening, gain saturation effects and dependence of the medium polarisation on the population inversion value, this approach is clearly insufficient. In this case, it is necessary to use a model based on the semi-classical Maxwell-Bloch equations [2,3]. An active medium with inhomogeneous broadening of the lasing line is described by a system of Bloch equations, which relate the dynamics of populations at the corresponding energy level to the dynamics of partial polarisations under the influence of signal and pump fields. The propagation of laser radiation in a medium can be described by the Unidirectional Propagation Equation (UPPE). Numerical simulation results of the proposed system of equations for a four-level medium are presented in this paper. The features of the formation of an electron lens under longitudinal pumping under conditions of gain saturation and inhomogeneous lasing line broadening during amplification of broadband chirped laser pulses are shown.

This work is supported by the Ministry of Science and Higher Education of the Russian Federation (Project No. FFUF-2024-0038)

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Experimental study of the effect of laser contrast on the duration of an X-ray pulse

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The temporal characteristics of X-ray radiation generated in the laser plasma of aluminum targets in the energy range of $1,5 \div 2,1$ keV were investigated on a femtosecond laser setup. The quanta with the required energy were separated using a total external reflection spherical mirror and an absorption filter. An X-ray streak camera with a picosecond time resolution was used as a recording device. A saturable absorber and plasma mirrors were used to increase the contrast of the laser pulse. Measured X-ray flash duration is 22 ± 7 ps without using a saturable absorber and plasma mirrors. The use of a saturable absorber reduces it to 11 ± 3 ps, and when both techniques are applied simultaneously the duration does not exceed 7 ps.

Elastic-plastic transition in nanocrystalline aluminum with various grain boundaries

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Effect of GB structure and specific energy on mechanical response and elastic-plastic behavior of Al was investigated. Tilt and twist [100] GBs with various misorientation angles were considered. HAGBs with different specific energy demonstrate a significant spread of critical stresses, differing up to 3 times in the case of tilt GBs. For LAGBs, there was no spread of results. The smallest activation stress for tilt GBs was about 200 MPa, the largest – 1800 MPa. For tilt HAGBs, the predominant plasticity mechanism is GB sliding, while for LAGBs, it is GB migration. The transition from HAGBs to LAGBs is accompanied by gradual increase in the number of systems in which GB migration is observed. For twist GBs, a similar tendency to critical stress decrease with an increase in the GB misorientation angle was observed. The results of MD are generalized with ANN, which is used in continuum approach as constitutive relations for elastic-plastic behavior of Al. Using SPH with ANN, the deformation of a representative volume with different GBs was simulated. In the case of one type of GBs, the stress evolution largely repeats MD system. With random GB distribution, an averaged and fairly stable stress-strain curve is obtained. Inclusion of only GBs with maximum or minimum energy for a given type GBs has little effect on the stress-strain curve. Twist HAGBs significantly reduce the flow stress at the initial stages of shear. Random distribution of GBs leads to plastic localization.

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Investigation of energy spread in laser-wakefield acceleration of electron bunch in non-linear regime

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The success of laser-wakefield accelerators (LWFA) depends significantly on the ability to provide quasi-monoenergetic acceleration of short electron beams to high energies [1–3] while maintaining low emittance. One of the limitations of LFWA is related to the intrinsic field of the accelerated beam arising due to its motion in the plasma (beam-loading effect) [4]. This backward influence effect limits the charge that can be accelerated because the longitudinal component of this field has the opposite sign compared to the original accelerating field of the traveling wave, which mainly affects the acceleration rate of the beam tail. This leads to a decrease in the energy of particles in the tail of the beam in particular, to a decrease in the energy of the beam as a whole, and, consequently, to a larger spread in the energy of accelerated particles for large beam charges [5]. Therefore, consideration of this effect is a very important task, especially if the goal is to obtain accelerated beams with as small energy spread as possible. In this paper we will consider and analyze the propagation and acceleration of an electron beam in a plasma wakefield excited by a laser pulse, as well as the influence of the beam-loading effect on the accelerated electron beam parameters.

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Dynamics of relativistic electron beam propagation

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In this study, analytically and using numerical modeling using the PIC method, we examine the propagation in a vacuum chamber and the change in the characteristics of a beam of relativistic electrons on the way from the plasma target in which it is generated to the equipment that records the electron beam or to a sample that is irradiated by electrons. In high-current beams, characteristic of the conditions of the analyzed experiments, the transverse motion of electrons can only be described in a relativistic approach. The solution of the corresponding equations shows that the trajectories of beam electrons reach an asymptotic dependence, in which the angle of inclination of the electron trajectory to the beam axis is determined only by the initial energy of the electrons, whereas when low-current beams are described using non-relativistic equations, the beam dynamics are determined by both its energy and charge [1]. For the parameters discussed, the analysis indicates a small role of electrostatic repulsion of relativistic beam electrons accelerated in the DLA mode during their transportation in a vacuum chamber. However, with an increase in the energy of the laser pulse and a proportional increase in the current carried by electrons, the influence of the electrostatic and magnetic self-action of the beam on its propagation in the vacuum chamber increases. In addition, as the beam charge increases, relativistic effects can affect the change in the electron concentration in the radial direction.

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Photonic annealing of thin-film conductive coatings by pulsed optical radiation

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Thin-film conductive materials are used in the production of flexible electronics. Conductive components (metal or graphene nanoparticles) and semiconductor structures (ITO, FTO) require sintering to achieve acceptable conductivity [1]. However, this is difficult on flexible substrates, since in most cases non-heat-resistant plastics (for example, PET) are used. Therefore, the traditional thermal annealing method is not applicable. An alternative method of post-processing films is the method of annealing with pulsed xenon lamps [2], [3]. The pulsed nature of the radiation makes it possible to anneal the film without significant impact on the substrate. In this work, the results of photonic annealing of thin-film conductive coatings by pulsed optical radiation from a pulsed xenon lamp with an energy density of up to 5 J/cm2 are carried out. The JG ST2253 four-probe measuring unit (Jingle Electronics Co., China) is used to measure the conductivity characteristics of the samples. Optical characteristics of thin-film images are measured using a TUV9 DCS dual-beam spectrophotometer (SILab, China).

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Development of QED-cascade arising at reflection of a PW laser pulse from a solid nanostructured target

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Quantum electrodynamics (QED) cascade arising in a superposition of incident multipetawatt laser pulse and its reflection from a solid target were studied. It is numerically [1] shown that with normalized laser field amplitude $a_0 = eE_0/(mc\omega) = 250$, pulse duration 120 fs and density $n_e = 500n_{cr}$ (which approximately corresponds, for example, to a diamond target; $n_{cr} = m\omega^2/[4\pi e^2]$), it is possible to obtain QED cascade in this setup. The growth rate of the number of particles is very close to that in ideal linear-polarized standing wave [2]. Consequently, it is not necessary to use multiple laser channels to observe a QED cascade as it was suggested earlier [3, 4]. One laser channel and a reflective plasma target are sufficient, which can make the experiment more simple for a lack of necessity of operating with multiple laser pulses and its precision synchronization.

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Hydrodynamic and thermomechanical effects in composite materials under intense energy flux exposure

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A computational model is presented in this work for the study of thermomechanical and hydrodynamic effects in composite materials under intense energy flux conditions. The model simulates heating, vaporization, gas dynamics, and solid deformation, allowing for the investigation of their interdependencies [1]. The simulation results can be applied for predicting the performance of composite materials in various high-energy applications and guiding the development of new materials with enhanced resistance to extreme environments.

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Primary converts of ionizing radiation fluxes of high energy density based on diamond

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The report provides an overview of the current state of diamond detector technology for recording high energy densities of ionizing radiation.

The results of the development of VNIIA means of specialpurpose measurements – diamond dosimeters (maximum measured exposure dose rate is up to 10^{11} R/s with a time resolution of at least 0.5 ns) and diamond dosimeters (maximum measured exposure dose rate is up to 10^{12} R/s with a time resolution of at least 0.2 ns). The nearest perspectives for the development of diamond instrumentation are shown as the latest achievements of the developers of the institute's division.

In the interests of radiation monitoring-optical measuring channel based on diamond scintillation primary converter with possibility of recording pulsed braking radiation with the maximum absorbed dose rate from 10^{-7} to 10^{4} Gr/h: a small-sized radiation-resistant neutron detector with a time resolution of at least 1 ns and a sensitivity of at least 10^{-17} C*cm^4.

In the interests of developers of controlled thermonuclear fusion (TCF) installations: CDWW-type soft X-ray detector (coaxial diamond without window) – a calorimeter with subnanosecond time resolution; measuring channel for measuring burning kinetics on TCF installations; hybrid small-sized radiation-resistant X-ray and neutron detector. In the interests of the Ministry of health and social promotion: small-sized tissue equivalent absorbed dose dosimeter to accompany radiotherapy procedures.

Reconstruction of the bremsstrahlung spectrum of electron accelerators

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Knowledge of the bremsstrahlung spectrum of electron accelerators is important not only for conducting research and testing for radiation resistance, but also for determining the attenuation factors of x-ray protective coatings. The existing techniques of spectrum reconstruction give solutions that result from incorrectly formulated problems. Use of supplementary a priory information and specialized regulation methods (for example, ridge regression) is necessary for such problems [1]. The experimental data is obtained with the absorption method. The spectrum is reconstructed by the solution of a linear first kind Fredholm integral equation. The problem is incorrect and has more than one solution. Besides, the input (experimental) data have measurement errors. The linear first kind Fredholm integral equation solvers were considered. We obtained the differential bremsstrahlung spectrum of the electron accelerator and the estimates of the confidence limits for statistical momenta (average value and dispersion) and for the group spectrum values. The code PRIZMA was used to calculate the electron bremsstrahlung in a diode assembly of the electron accelerator.

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Measuring the viscosity of liquid sulfur by proton microscopy

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Sulfur exhibits an unusual dependence of viscosity on temperature. An experimental setup was developed to study the viscosity of sulfur at pressures up to 100 bar and temperatures up to 500 °C. Proton radiography was used to visualize the fall of a tungsten carbide ball placed in molten sulfur. The experiment was conducted using the PRIOR II proton microscope (GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany). In this experiment, the SIS-18 accelerator operating mode with slow beam extraction was used for proton radiography for the first time. The viscosity of molten sulfur was measured at a pressure of 90 bar and temperatures ranging from 190 to 320 °C. It has been shown that impurities, including hydrogen sulfide, which appears in the sulfur melt at high temperatures, have a significant effect on the viscosity of sulfur.

The laser surface treatment of 3D printed Ti6Al4V samples

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The results of a study of laser surface treatment of Ti-6Al-4V samples obtained using 3D printing are presented. Laser treatment was performed by immersing the sample in water. The thickness of the resulting surface layer after laser treatment was 30-40 microns. It was found that the laser treatment leads to oxidation of Ti-atoms with formation of unstable TiO (Ev=455.1 eV) and Ti_2O_3 (Eb=457.4 eV) oxides. A comparison is done with literature results associated with surface treatment of the titanium 3D printed products for medical use.

Suspension freezing as a novel approach for increasing the efficiency of the Laser-Induced Breakdown Spectroscopy method in the study of nano and submicron particles

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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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Experimental study of aluminium K-line generation using planar multi-wire arrays

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The results of a series of experiments on powering planar aluminum arrays with a current pulse of 2 MA with a rise time of 1.1 mks are given. The number and the diameter of aluminum microwires were varied in the experiments. The height and the width of the array plane were unchanged. A control experiment was carried out with a planar array made of tungsten microwires. X-ray diodes and bolometers with filters made of various materials were used to record parameters of the generated X-ray pulses. Powerful X-ray pulses with quantum energy above 1 keV were recorded in experiments with aluminum microwires (the maximum energy measured by a bolometer behind a lavsan filter is 2 kJ/cm), which indicates the presence of an aluminum K-line in the resulting radiation spectrum.
The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 "Research in high and ultrahigh magnetic fields"

Observation of 18 MeV electron beam spot dynamics and accompanying disassemble of target in double pulse mode of LIA

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This report describes well known problem of beam-target interaction in multi pulse mode of linear induction accelerator (LIA) [1, 2]. Electron beam (18 MeV, 1.5 kA, 150 ns, double pulse) focused into millimeters spot size on a tantalum plate with a thickness of 1 to 3 mm was studied. The basic diagnostics are described, especially the multi-pixel detector [3] based on a scintillation fiber (decay times 3 ns). First experimental data are considered and hypothesis of beam-plasma interaction is discussed.

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Fiber optical detector for foreign object damage of composite turbine blade

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Composite fan and stator blades of the turbofan engines are subjected to damage caused by high-speed foreign objects (hail, rocks, debris). So it is important to detect such events and their consequences. Especially when initial damage leads to progressive damage of an element due to cyclic and static load. Traditional gages such as acoustic emission sensors are hard to place on the blade avoiding aerodynamic or structural strength problems. Fiber optic Bragg sensors can be easily integrated into the blade, but have limited bandwidth to detect short events. We propose interferometer-based distributed fiber-optic sensor where one leg of the interferometer is the sensor fiber evenly distributed inside the blade. Acoustic waves caused by impact or acoustic emisson of fiber breaking cause deformation of the fiber and lead to change of its optical length. Bandwith of the sensor is mainly limited by the diameter of the optical fiber and its shielding like for manganine gage. The proposed sensor's advantages are its high bandwidth and ability to detect both the impact event and consequent damage evolution. Disadvantages are lack of location ability and complexity of the signal because acoustic wave passes optical fiber multiple times on its way. 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).

Efficient handling of THz radiation from relativistic laser interaction with liquid jet

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The generation of THz radiation from relativistic laser-plasma interactions is currently being actively investigated [1, 2]. In this paper, methods for detecting THz radiation obtained in the interaction of a relativisticly intense laser pulse with a preionized target – ethanol jet with a thickness of tens of micrometer have been developed. The regime of generation of an electron beam with a large divergence usually corresponds to a higher beam charge, and, subsequently, to a higher energy of transition radiation in the THz frequency range. However, this regime also leads to the generation of THz radiation at wide angles due to the low average electron energy. Therefore, to collimate THz radiation generated at relatively wide angles, we propose to use a special parabolic concentrator with acceptance of angles from 45 *extdegree* to 90 *extdegree*. This study was conducted within the scientific program of the National Center for Physics and Mathematics, section 4. Stage 2023-2025.

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Interaction of femtosecond laser radiation with gold foil: molecular dynamics simulation

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We study the melting of a thin (35 nm) golden foil irradiated by ultrashort laser pulses (duration 130 fs). Calculations were done within classical molecular dynamics with a highly-optimized EAM potential by Sheng et al (Phys. Rev. B 83, 134118, 2011). Laser pulse (LP) absorption by electrons and energy transfer from electrons to the crystal lattice were described with a two-temperature model. Absorbed energies from 0.18 to ∼2 MJ/kg were studied. The calculated time of complete foil melting as a function of absorbed LP energy is compared with experimental data. Also compared with experiment is the temporal evolution of the diffraction peak (220) after target irradiation. Calculations were done for a number of the currently available dependencies of the gold electron-phonon coupling factor on electron temperature. The accuracy of these dependencies is discussed.

Complex electrical, mechanical and thermal effects on the structural elements of mega-ampere plasma focus chambers

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Plasma focus (PF) devices are one of the most powerful sources of pulsed neutron radiation due to the nuclear fusion reactions of hydrogen isotopes [1]. When plasma focus chambers are operating as a part of this powerful devices with mega-ampere discharge currents, serious complex effects are applied to the electrodes and the Insulating unit of the PF chambers. The gas-discharge plasma located in the PF chambers in the form of a moving current-plasma shell and a high-current pinch discharge has mechanical, thermal and electrical effects due to its accelerated movement, high discharge current and pinch collapse, respectively. The paper presents experimental results of the operation of PF chambers in a device with a discharge current of up to 1.2 MA, shows the results of the listed effects and examines the relationship between electrical, mechanical, temperature effects and changes in the construction of PF chambers and their performance characteristics.

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Cherenkov radiation influence decreasing in scintillator-based fiber-optic detectors

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The one of possible ways to protect photosensitive elements of scintillation detectors from the ionizing radiation is removed them from irradiation area. In this case the link between scintillation and photosensitive parts is could be made by optic waveguides. Those devices were named scintillator-based fiber-optic detectors. The one of main problems of that systems is Cherenkov radiation, which appears as reaction scintillator and fiber-optic line on a powerful ionization irradiation.

In this work the scintillator-based fiber-optic detector with up to 100 meters multi-fiber line was shown. The detector feature was based on using signal and reference channels which forming symmetrical measuring scheme. The difference between channels is the sensitive media in the reference one. For reference channel we used the same scintillator polymer structure without wavelength-shifters compounds. We demonstrate that in this case Cherenkov radiation contribution in a measured signal could be fixed and effectively reduced by simple calculations.

Investigation of cumulative processes of light nuclei production in interaction of heavy nuclei with energies in a range of 1-10 GeV/nucleon

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An analysis of experimental data obtained with extracted relativistic carbon, argon, and krypton ion beams at Nuclotron (LHEP JINR) is presented. The specific features of experiments using the head part of the slow-extraction channel of Nuclotron as a magnetooptical spectrometer are discussed. A method for measuring and analyzing time-of-flight spectra with a temporal resolution of ¡50 ps is described. Unique data on the simultaneous acceleration and extraction of carbon, nitrogen, and oxygen nuclei from Nuclotron are presented. The possibilities of simultaneous acceleration of ions with similar charge-to-mass ratios are discussed. Spectra of nuclear fragments in the region kinematically forbidden for nucleon-nucleon interactions are analyzed. The upgrade of the head part of the Nuclotron slow-extraction channel for future research is presented.

MCP based detectors for registration of circulating accelerated beams and single charged and neutral particles

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The results of development and practical implementation of detector systems for circulating beams of the accelerator complex NICA (LHEP JINR) are presented. The advantages and disadvantages of detectors based on MCP (Microchannel Plates) are discussed. The specific features of MCP chevron assemblies, their characteristics, as well as various signal readout systems, are demonstrated. The report is illustrated by a wide range of experimentally registered dependencies obtained during the operation of these systems in the internal vacuum chambers of the Booster and Nuclotron accelerators of the NICA complex. A new type of detector for registering thermal neutrons based on a radiator made of boron-10 isotope and a chevron microchannel plate assembly is presented. Optical image registration systems using a luminophore screen of this neutron detector and various types of CMOS matrices are discussed.

Incoherent illumination system based on synthetic diamond for shadow recording of fast processes

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The possibility of creating a high-brightness pulsed light source in the visible wavelength range with low temporal coherence based on synthetic diamond for highlighting fast moving objects during shadow registration with a photographic plate or digital camera in gas dynamic experiments has been numerically and experimentally investigated.

The use of a pump picosecond laser combined with a light converter based on synthetic diamond containing NV-color centers as a illumination system makes it possible, while maintaining high brightness and a short duration (less than 1 ns) of an illumination pulse, to increase the resolution of the shadow registration method several times. High resolution is achieved by reducing the temporal coherence of the illumination light due to broadening its spectral band in a diamond plate with a wide gain line in the visible region of the spectrum placed in an optical resonator.

The report presents the results of theoretical calculations of the main parameters of the proposed pulsed light source and the results of the first experiments on its creation.

Relativistic nuclear physics at the LHEP accelerator complex

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Methodological problems of investigations in the field of relativistic nuclear physics are considered. Basic notions and principles underlying the construction of scientific description of physical phenomena in the field of relativistic physics are discussed. Definitions of variables used for description of relativistic nuclear collisions are given. Various definitions of cumulative and collective processes of nuclei interaction are discussed. The role and significance of the Lobachevsky geometry in description of relativistic phenomena, in particular, particle production, are presented. The notion "elementary particle" is discussed. The problems of goal setting and optimization of experiments planned at the accelerator complex NICA are addressed.

Critical behavior of conductivity in the quantum Hall effect regime: interaction effects

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The lively interest in the study of two-dimensional gas in HgTe/CdHgTe-based structures is caused by the diversity of properties of these systems associated with the complex nature of their energy spectrum. In particular, at the critical width (6.3 nm) of quantum well (QW), a dispersion law similar to that of massless fermions in graphene is realized. The quantum Hall effect (QHE) in such systems is observed up to room temperatures in graphene and up to nitrogen temperatures in HgTe, which provides new opportunities for analyzing the predictions of scaling theory regarding the critical behavior of conductivity in plateau-plateau and plateau-insulator quantum phase transitions in the QHE regime. Both systems, graphene and HgTe-based QW as well as GaAs-based structures, demonstrated the importance of taking into account the scale of the random potential and the interparticle interaction when discussing the universality of the experimentally obtained values of critical exponents.

In this study, we discuss experimental results obtained on different two-dimensional semiconductor structures characterized by strong spin-orbit and electron-electron interactions, and focus on identifying the influence of the spin degree of freedom and topological features of the studied systems on the problem of the universality of critical exponents obtained when describing transitions between different quantum Hall liquids in the QHE regime. As a topologically nontrivial system, we consider a heterostructure with a HgTe-based double QW with layers of critical width.

Investigation of the processes of formation of the crystalline phase in layered amorphous-crystalline ribbons produced of Ti50Ni25Cu25 alloy during electric pulse treatment

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The effect of electric pulse treatment (EPT) on the microstructure of rapid-quenched layered amorphous-crystalline ribbons obtained by spinning a Ti50Ni25Cu25 melt on a rapid rotating copper disk has been experimentally investigated. A sequential series of samples of Ti50Ni25Cu25 alloy ribbons was obtained after EPT by a single pulse of electric current with a duration of 1 ms with an increase in the degree of heating before and after reaching the recrystallization temperature of the amorphous part of the ribbons. This treatment makes it possible to heat up the ribbon samples in a short time and carry out crystallization without isothermal exposure. As a result of the EPT, a sequential series of experimental samples of ribbons with various degrees of processing was obtained: from the state "without changing the structure" to the state "completely crystallized". The microstructure of the obtained samples was studied and the stages of EPT were determined. It is shown that the EPT method in layered amorphous-crystalline tapes can change the ratio of amorphous and crystalline phases, form structures with different layers and modify the shape memory effects. This research was funded by the Russian Science Foundation (project No. 24-22-00035).

Generation of X-rays in cluster jets by relativistic laser pulses.

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Generation of X-rays by laser pulses on a target is developing along with the increase of accessible, routine laser intensity. The main advantages of the laser generation method are: sub-picosecond duration and point size of the source, synchronization with a powerful laser pulse for application in ”pump-probe” methods, the possibility of obtaining both narrow-band and broadband X-rays. The goal is to study the generation of characteristic, bremsstrahlung X-rays during the interaction of laser radiation of relativistic intensity with a jet of clusters to compare with the case of copper foil [1]. To evaluate the possibilities of γ-radiation from accompanying accelerated electrons. The studies were carried out at the NRC ”Kurchatov Institute” on a Ti:Sa laser complex with 300 mJ energy , 30 fs duration and 10 Hz rep.rate [2]. The cluster target was created by expanding the gas (5-35 bar) through a supersonic nozzle. Ar, Kr, N_2 and O_2 were used. The dependencies of the X-ray yield on the pressure and type of gas, energy and duration of the laser pulse were studied [3]. The optimal focusing point in a target with non-uniform density was determined. The maximum spectral brightness was achieved for K_α Kr 3×10^8photons/($4\pi\times$pulse) (conversion efficiency 4.2×10^{-6}), comparable with copper targets 5×10^8photons/($4\pi\times$pulse) (efficiency 10^{-5}) [1]. γ-radiation was obtained from a beam of relativistic electrons in a 1 cm thick converter with an exponential spectrum with a “temperature” of 285 ± 65 keV in the range of $2.5 - 7$ MeV and a divergence of 40° at the 1/2 level.

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Cosmological constant due to quantum corrections to the effective potential

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In this work, we show that quantum corrections to some cosmological models [1] can lead to a significant modification of the behaviour of the initial potential and the appearance of a non-zero ground state energy of the Universe which can be interpreted as a cosmological constant. We apply the formalism of the effective potential to the simplest forms of α-attractors which can be represented by the so-called T-models and E-models [2]. We derived the generalised renormalisation group (RG) equations that sum up the whole sequence of leading logarithmic contributions to the effective potential. As a result, the accounting of quantum corrections leads to a change of character and a lift of the effective potential [3, 4]. We interpreted this uplift as the appearance of the cosmological constant Λ for the T^2 and E^2 models. Thus, we have found out that the cosmological constant Λ may exist as a consequence of quantum corrections to the effective potential with some value of the scale transmutation parameter μ even in non-renormalizable models of inflation. And the value of the cosmological constant Λ allows one to fix the parameter μ which is a free parameter in the non-renormalizable theory.

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[3] Kazakov D I, Iakhibbaev R M, Tolkachev D M and Filippov V A 2024 *PoS* 022
[4] Kazakov D I, Iakhibbaev R M, Tolkachev D M and Filippov V A 2024 *Natural Science Review* (*Preprint* `2405.18818`) URL `https://arxiv.org/abs/2405.18818`

Absorption of a twisted photon by an electron in strong magnetic field

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The work investigates the absorption of a twisted photon, which is a photon possessing orbital angular momentum, by a relativistic electron with the Lorentz factor $\gamma \sim 1 - 10$ in a strong magnetic field up to the Schwinger limit, $H_c = 4.4 \cdot 10^{13}$ G. We examine the absorption cross sections and their dependence on the parameters of the incident photon and the initial Landau electron. It is found that total absorption cross sections decrease as angular momentum of the incident photon increases and increase as angular momentum of the initial electron grows. The process is also compared across different magnetic field strengths, and the contribution of various electron spin transitions to total absorption cross section is analyzed. We also find that the processes without an electron spin flip dominate and, on top of that, an asymmetry in the “spin-down” $\rightarrow$ “spin-up” and the “spin-up” $\rightarrow$ “spin-down” transitions is observed. Specifically, the cross sections for the “spin-down” $\rightarrow$ “spin-up” transition are larger, which can be interpreted as an analogy of the Sokolov-Ternov effect present for photon emission [1–3]. Finally, the cross sections are found to be almost constant as the transverse momentum of the photon varies from 0.1 eV to 100 keV. Our findings can help to improve the understanding of the QED processes in critical fields, typical for astrophysical environments, e.g. magnetospheres of neutron stars.

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Self-similarity method in relativistic physics

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Particle production in nuclear collisions is quantitatively described using the self-similarity method. The method is based on the self-similarity description of production cross sections as functions of fractions of four-momenta of particles participating in the reaction. This allows one to describe a wide variety of reactions in a unified way. The validity of this description was proved using multiple experimental data. The future experiments at the LHEP accelerator complex on strangeness production are simulated using the self-similarity method in order to set up measurements in an optimal way. A wide range of types of colliding nuclei and energies from units to tens of GeV obtained using the bubble chambers is analyzed using the self-similarity method. Special attention is paid to cumulative processes with high transverse momenta and soft processes not related to collective effects in relativistic nuclear interactions.

Substitution solid solution from boron vapor saturated liquid carbon

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Liquid carbon saturated with dry boron vapor was experimentally obtained at laser induced process. It was established that vapor solution solidified as a graphite-like solid solution (C-B_{SS}) under conditions of diffusion inhibition at rapid quenching. However, at quasi-equilibrium process and absence of inhibition the vapor solution was solidified as B_4C. Atomic concentration of boron in C-B_{SS} at rate 4.7% [1] enables recommending it as a precursor for boron-doped diamond at direct phase transition graphite to boron at HT-HP process. It is known that boron-doped diamond at $[B] > 1\%$ possesses superconducting properties under strong magnetic fields, but catalytic HT-HP process permitted only $[B] < 1\%$.
Atomistic modeling of the quenching was performed by molecular dynamics with a machine-learning potential and, therefore, identified C-B_{SS} as a substitutional solution, where boron atoms replace carbon atoms in amorphized graphite. The explanation of the specific corrugated form of graphene layers was suggested. These are mechanical stresses caused by the pentagonal motif imposed by the introduction of a boron atom into the graphite lattice. The modeling of quenching was processed in the molecular dynamics package LAMMPS [1] with the GAP potential model [3], specifically developed for distinct molecular configurations involving B, N, C and they chemical species. The reliability of the potential was validated by comparing structural characteristics calculated using DFT-MD over a temperature range from 300 to 5000 K.

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[2] Plimpton S 1995 *Journal of computational physics* **117** 1–19
[3] Kaya O, Colombo L, Antidormi A, Lanza M and Roche S 2023 *Nanoscale horizons* **8** 361–367

Photoluminescence and radioluminescence spectra and temporal dynamics of γ-rays scintillators

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For the registration of ultrafast γ-pulses, efficient detectors with subnanosecond response time are needed. So, the development of efficient, fast, and robust scintillators for ionizing radiation detection is an important problem in modern high-energy particle physics. Typically, it is difficult to achieve optimal performance and high-speed operation of the scintillator at the same time. A new class of scintillator based on quantum shells opens a way to solve this problem.

In this work, we performed a comparative analysis of photoluminescence and radioluminescence properties of traditional plastic, inorganic, and colloidal quantum shells scintillators. Photoluminescence data were collected using a pump generated by a femtosecond Ti:sapphire laser, with emission collected by fiber and directed onto a visible-range spectrometer. Time-resolved emission was registered by a streak camera with 5 ps resolution. Radioluminescence spectra and temporal dynamics of scintillators were investigated under excitation by γ-ray pulses with picosecond duration.

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 nonresonant 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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Quality assurance of the post-processing after straightening performed with a nanosecond uv-laser

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When performing microstamping operations at different similarity ratios, it is often encountered that it is not possible to design the radii of rounding of a sheet blank. This is due to both an increase in the stiffness of the workpiece as the ratio of the thickness of the workpiece to the average grain size (t/d) decreases, and to the rheological characteristics of the material itself or its ability to resist deformation depending on the deformation rate. In addition, the elastic properties of the workpiece will also be responsible for the stiffness of the workpiece, the tendency to spring back as a result of the Bauschinger effect. Experimental results of drawing/bending operation show that at $\lambda = 0.5$ and 0.25 there is a deviation from the radii of rounding of the die corners for copper M1 and brass L63. Subsequent straightening does not result in full filling of the radii. Application of serial exposure to nanosecond uv-laser radiation makes it possible to bring the rounding radii closer to the drawing radii without performing straightening operation. The values of stresses arising in the investigated materials at forming operations, as well as during straightening by UV-laser pulse have been determined by means of numerical modeling. Comparison of the initial and actual geometry of the "plate" parts was performed using a non-contact three-dimensional-scanning system based on the structured light.

Trajectories of charged microparticles in a linear quadrupole trap with a rectangular potential

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A new application of electrodynamic traps can be the rapid determination of the size and charge of particles from trajectories of motion in air, as well as the study of chaotic particle motions that can arise from simple oscillations. The behavior of Coulomb systems and individual microparticles in a quadrupole linear trap is well studied for the harmonic form of the confinement voltage. In the case of harmonic voltage, only amplitude and frequency can be changed to influence the held particles, while in the case of rectangular voltage form, additional variable parameters are: different durations of positive and negative pulse while keeping the total duration of the period constant, as well as different amplitudes of positive and negative polarity pulses.

The trajectories of micron-sized charged particles in a linear quadrupole trap in air with a new form of potential in the form of rectangular alternating periodic pulses at the linear electrodes of the trap have been investigated. The shapes of trajectories of charged dielectric particles of micron size at rectangular pulse confinement voltage with different filling factors of the positive polarity of the pulse have been experimentally and numerically obtained.

Nonlinear absorption of femtosecond laser pulses in PMMA

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Owing to its excellent physical and chemical properties, polymethylmethacrylate (PMMA) remains the basic soft-matter polymeric material platform for multiple photonic applications and investigation of nonlinear optical parameters of ultrashort laser pulses – PMMA interaction is of great interest [1, 2]. Based on the experimental measurement of the nonlinear transmission coefficient of 1-mm thick plane-parallel plate made of PMMA irradiated with tightly focused (NA=0.25, focal length f'=16 mm, 1/e^2-intensity focal spot radius $w_0 \approx 3.5 \pm 0.5 \mu$m) 1030-nm laser pulses with 250 fs duration, the nonlinear dependence of this parameter on the pulse energy was established by the I-scan method. It was found that in the range of intensities not exceeding the threshold value of $I_{th} \approx 10$ TW/cm^2 the main mechanism of laser pulses attenuation is 8-photon absorption (excited energy level 8×1.2 eV ≈ 9.6 eV, coefficient $\beta_8 = 3 \times 10^{-5}$ cm^{13}/TW^7) implying photoionization of the PMMA chains. The nonlinear transmission measurement of weakly focused laser pulses (f'=200 mm, 1/e^2-intensity focal spot radius $w_0 \approx 22 \pm 1 \mu$m) based on the z-scan method made it possible to estimate the value of the nonlinear refractive index of PMMA $n_2 = 5.5 \times 10^{-4}$ cm^2/TW. The obtained results were confirmed by near-IR femtosecond laser induced permanent refractive-index modifications and MMA-related changes in Raman spectra of the studied PMMA sample. This research is supported by Russian Science Foundation (project no. 25-22-00488).

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Reconstruction of Z-pinch emission spectra in the wavelength range of less than 10 Å using a crystal X-ray spectrograph

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This work is devoted to the reconstruction of Z-pinch plasma emission spectra in the wavelength range of less than 10 Å recorded by using a crystal x-ray spectrograph at the Angara 5-1 mega-ampere facility. The spectrograph JA-1 used in experiments has a cylindrical mica crystal with dimensions of 50 *imes* 40 mm^2 and radius of curvature of 100 mm. Registration of spectra is performed on the photographic film UF-4 with dimensions of 30 *imes* 10 mm^2. To reconstruct the spectra, the previously developed method based on iterative approximation of a true spectrum shape while minimizing a residual between experimental and calculated spectrograms is used [1,2]. The calculated spectrogram was obtained taking into account the instrumental function of the spectrograph. To define the instrumental function a virtual Monte-Carlo model in the Geant4 toolkit has been developed [3]. This model takes into account the interaction of radiation with the mica crystal using dynamical theory of diffraction. A true spectrum of Z-pinch plasma radiation is reconstructed for a load made of Al wire liners.

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[3] Skobliakov A V *et al.* 2024 *Review of Scientific Instruments* **95** ISSN 0034-6748

Spectral broadening of laser pulse during generation of powerful THz radiation from gas-cluster target

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Gas plasma is a promising source of terahertz radiation, enabling conversion of intense ($> 10^{18}$ W/cm^2) laser pulses with relatively high efficiency. THz radiation is created by accelerated relativistic electrons, with transition radiation being the only thoroughly studied mechanism, mostly coherent [1], rarely incoherent [2]. Gas-cluster targets are more promising for THz generation than solid-state ones, providing high local density and necessary transparency without contaminating the interaction chamber. Through experiments at the terawatt laser facility at the NRC “Kurchatov Institute” (800 nm, 30 fs, up to 310 mJ in this series, up to 10 TW) electrons were efficiently accelerated to 10 MeV, capable of generating terahertz radiation with energy up to 20 μJ, in 10 nm nitrogen and oxygen clusters. The obtained radiation has a spectrum up to 3 THz and conical divergence at $\approx 20^\circ$ with nearly circular polarization outside the vacuum chamber. THz demonstrates a full correlation with electron charge, while synchronous analysis with visible spectra modification provides deeper understanding of laser plasma processes, particularly electron concentration. Visible spectra are shown to be a convenient criterion for optimizing THz generation mode, with THz field intensity potentially exceeding MV/cm at the point of further use. Together, all signals provide a platform for picosecond time-resolved studies, where THz, electrons and laser can interchange roles between pumping and probing.

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Optical resistance of polymer materials when exposed to shortwave ultraviolet radiation

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Polymer materials are widely used in aerospace engineering due to their low density, flexibility, and durability. The influence of external factors of outer space, can cause changes in their operational properties: chemical composition, mechanical strength, optical properties. Work on the mechanisms of polymer degradation [1] shows that the main influence on optical properties is exerted by radiation in the range of 200-280 nm (UV-C range). To assess the durability of new promising and already used materials used in the rocket and space products, a cycle of ground tests using solar radiation simulators is necessary [2], [3]. The paper presents the results of testing polymer materials at an accelerated optical stability testing facility. An pulsed xenon lamp is used as a radiation source in the installation. An accelerated optical stability test of polymer materials, PET and siloxane rubber, has been performed. The material samples were irradiated with doses of UV-C radiation corresponding to a stay in orbit from 1 week to 1 year (according to ASTM E-490 AM0 Standard Spectra 2000). The analysis of changes in the optical properties of the samples under the influence of radiation is carried out. The presented data were obtained using a TUV9DCS spectrophotometer (SILab, China).

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Non-lineartity in pulse cathodoluminescence and radioluminescence due to interactions between electronic excitations at their high densities

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Previously we proposed an experimental method for studies the scintillation non-linearity of wide-gap materials based on analysis of pulse cathodoluminescence (PCL) spectral and kinetic properties on parameters of an exciting electron beam [1]. In particular, this method allows to investigate the dependence of PCL parameters on the volume density of electronic excitations (EEs) created by the beam [1, 2]. Using this method, we estimated the EE densities produced by an electron beam generated by a RADAN-EKSPERT accelerator [3,4] and the dependenceis of PCL parameters on the EE densities for different oxides and fluorides. For some materials, these results were compared with the data on radioluminescence non-linearity. Physical processes inducing the scintillation non-linearity at EE densities of $\sim 10^{18}$ cm^{-3} and higher are discussed. The work is supported by Russian science foundation (project 19-79-30086-P).

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Dielectric ring as an analog of a magnetic dipole in GHz magnetic field

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We have demonstrated that a dielectric plane ring with a high permittivity excited by an incident plane electromagnetic wave in the GHz frequency range, is an almost ideal magnetic dipole for the basic resonance of incident radiation scattering. The scattering fraction of all other multipoles is insignificant and is less than 2×10^{-3} of the main magnetic dipole resonance. Experimentally measured magnetic field distributions near the ring are consistent with the results of computer simulation and the Biot-Savart-Laplace law. Thus, the Biot-Savart-Laplace law can be applied both to calculate conductive structures based on metal rings and to calculate non-conductive structures based on dielectric rings with low losses at GHz frequencies.

PVT-measurements of butylcyclohexane - n-decane binary mixture.

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One of the main factors emphasizing the importance of jet fuel research is the need to improve its energy efficiency. Modern research is aimed at creating cleaner and more economical fuels, which will reduce emissions of carbon dioxide and other harmful substances into the atmosphere. This, in turn, contributes to improving the environmental situation and meeting international environmental standards. Butylcyclohexane and its mixtures with hydrocarbons play a significant role in the chemical and energy industries, especially in the context of jet fuel utilization. This compound has a number of properties that make it attractive for use in aviation and other industries with high fuel quality requirements. One of the key factors in the importance of butylcyclohexane as a jet fuel component is its high resistance to detonation and good thermodynamic characteristics. This makes it possible to create fuels with improved performance properties that provide more stable engine operation, especially at high loads and temperatures. Butylcyclohexane-hydrocarbon blends can be tuned to achieve the desired octane number, which is critical to ensure optimal performance of internal combustion engines and jet engines. These blends help reduce the likelihood of detonation, which in turn improves combustion efficiency and reduces emissions. In this work we studied pvt- measurements of butylcyclohexane - n-decane binary mixture of 0.5 mole fraction. By using method of isochore break points we obtained phase transition points for six isochores.

Fundamental role of Saturn's magnetosphere in the origin of visible dense rings and the nature of repulsion force between ice bodies in it, predicted by J. Maxwell, 1856

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Participants of Cassini mission to Saturn (2004-2017) concluded there is no yet explanation of the origin of visible dense rings [1–4]. Such as origin of stable three-dimensional disk at equator, their fine structure and separation of ice bodies in the rings. We take into account diamagnetism of ice of dense rings [5] and solved problems by mutual action of gravity and magnetic field on ice bodies in the protoplanetary cloud of Saturn [6]. For the first time we determined diamagnetic nature of repulsion force of ice bodies of visible dense rings, predicted by Maxwell, 1856 [7, 8].

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2. *Shock Waves, Detonation and Combustion*

Spall strength measurements of epoxy resin with varying content of polyphenylene sulfone

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The utilization of thermoplastic materials has proven to be of interest for a multitude of applications. They can be employed as binders in polymer composites for structural purposes and can also be used as additives to existing highly heat-resistant but brittle thermosetting binders. The incorporation of materials such as polysulfone, functioning as a modifier, into epoxy binders has the potential to markedly enhance the crack resistance of the material. The present study has therefore been undertaken to experimentally investigate and assess the effect of the polyphenylene sulfone additive on the strength of epoxy resin. It has been previously established that, in static conditions, the addition of 5 percent polyphenylene sulfone to epoxy resin results in an increase of its strength. In this study, the spall strength of the epoxy resin samples was found to decrease with increasing polyphenylene sulfone addition under dynamic loading conditions. The attenuation of velocity oscillations in the spall plate is observed to vary with differing polyphenylene sulfone content. This finding indicates that the fracture kinetics and viscosity of the samples are distinct. The gradient of the spall pulse front is determined by the rate of pore growth when the material undergoes destruction, thus suggesting that the rate of failure may increase with the incorporation of polyphenylene sulfone content.

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

Excitation of detonation in an explosive composition based on TATB during shock wave initiation by plane shock waves with an amplitude from 8 to 12 GPa

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To verify models of detonation kinetics used in mathematical modeling of the operation of products containing explosives, data on shock wave initiation of detonation obtained in various model experiments are used. The main ones are experiments on the initiation of stationary detonation by shock waves of a rectangular (table-shaped) profile in the amplitude range from 2 to 20 GPa.
This paper presents the results of experiments to study the shock wave initiation of an explosive composition based on TATB to shock waves with a rectangular profile and an amplitude of 8-12 GPa.
The following data were obtained: the dependence of the depth of detonation excitation and the time of formation of the detonation regime on pressure, and the pressure profiles at the screen-explosive composition interface.
The experimental data obtained in the work were used to test the detonation kinetics models "MK" and "Ochag".
The research results can be used to calibrate and verify formal kinetic models of detonation.

Method for simultaneous determination of mass and wave velocities in radio-transparent materials based on microwave doppler diagnostics

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The method of microwave Doppler diagnostics has found a fairly wide application in the study of shock-wave and detonation processes, which is due to the possibility of propagation of probing radio radiation in various non-metallic materials, primarily in solid explosives, and acceptable accuracy in determining the velocities of shock and detonation waves. In some cases, in the absence of ionization of shock-compressed matter, it is possible to obtain information using the micro-wave method about two kinematic parameters at once-the wave and mass velocity, which are necessary for determining the shock-wave compression of materials.

In this paper, the algorithm for determining the wave and mass velocities in radiotransparent materials was improved, which made it possible to increase the accuracy of the experimental information obtained using the method.

To test the method, a series of experiments was carried out to study the shock-wave compressibility of polymethylmethacrylate (PMMA) in the pressure range from 3.5 to 13 GPa. Using the microwave diagnostic method, data on the mass and wave velocities were obtained in each experiment, and the dielectric constant of shock-compressed PMMA was estimated.

Self-ignition of pressurized hydrogen released into open space through gradually rupturing diaphragm

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The study demonstrates 2D numerical modeling of gaseous hydrogen release under high pressure into atmosphere through circular hole with gradually rupturing diaphragm. The cases of release with different initial hydrogen pressures, up to 700 atm, different hole radii, 2 to 20 mm, as well as different diaphragm rupture times are considered. The characteristic flow structure is obtained, which enabled to reveal that the development of self-ignition kernel occur on the side surface of hydrogen flow, but not on its central part, as in the case of release with instantaneous diaphragm rupture. The limits of self-ignition are obtained by varying diaphragm rupture time (or rate) and initial hydrogen pressure for different hole radii. The significant convergence of limits in terms "rupture rate – hydrogen pressure" is revealed, when using sufficiently small hole radii, 10 mm. A criterion for self-ignition based on characteristic time scales is discussed. The obtained results could be useful for setup of laboratory experiments as well as evaluation of risks of hydrogen self-ignition during accidental depressurization of hydrogen storage systems or hydrogen pumping from the high-pressure vessel into the combustion chamber.

This work is supported by the Ministry of Science and Higher Education of the Russian Federation (No. 075-15-2024-543, 24.04.2024).

Development and simulation of laser shock peening process for additively manufactured samples made from titanium alloy

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The report presents the results of comprehensive studies of the laser shock peening (LSP) process of additively grown samples made from titanium alloy. A theoretical model has been developed in respect of the multifactorial impact of laser hardening modes and boundary conditions on the characteristics and properties of the samples. The key parameters and the order parameter to which the other variables of the laser-plasma system are subordinated are established. The critical laser flux density was calculated corresponding to the optimal value of the pulsed pressure of the plasma torch on the sample surface. Numerical simulation of 3D printed samples was performed in the module Print 3D of the Altair Inspire software; optimization was performed using the Hopfield neural network. The distribution of residual stresses in a titanium alloy has been studied theoretically and experimentally as well. The triadic relationship "mode–structure–properties" was featured out and substantiated for the LSP process. The surface, subjected to laser shock peening, as well as the layers in cross-section were investigated, whereby such characteristics as microhardness, strain hardening, roughness, residual stresses, and critical deflection were determined experimentally. In particular, residual stresses were measured both by X-ray diffraction analysis using the "sin2ψ"-method on a StressX GNR residual stress analyzer and by non-contact surface photometry. Image analysis was performed using the OpenCV library for Python.

Generation of vortex structures by perturbed converging shock waves

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The flowfield in symmetric (cylinrical or spherical) converging shock wave is known to be vortex free. At the same time, converging shock waves are unstable with respect to symmetry preservation. Small disturbances of cylindrical or spherical flow symmetry tend to increase. This is accompanied by vorticity production, which increases rapidly in the vicinity of the focus. In the present work the vorticity production by spherical converging shock wave is investigated in the framework of the initial value problem for 3D Euler equations of gas dynamics formulated in converging frame. Carnahan-Starling equation of state is applied to take into account the influence of thermodynamic non-ideality due to the particle interactions. Moving (converging) grids allow to obtain an accurate solution to the problem in a wide range of the shock wave radius. Converging spherical shock wave is considered, which is perturbed by an asymmetric π-periodic disturbance with respect to rotation around an axis passing through the focus. The shock wave generates vortex surfaces (tangential discontinuities) outgoing from the lines of triple-shock configurations on the shock wave surface. Interactions of the vortex surfaces produce intence vortex formation within the structures of double Mach reflection. The calculations has shown turbulent nature of the flow near the focus at scale of the front pressure growth termination due to transition from Mach to regular interaction of the shock wave segments. The turbulent character of flow near the focus may be important for applications of converging shock waves for the purposes of initiating reactions (detonation, controlled thermonuclear fusion). The work was supported by the Russian Foundation for Scientific Research (No. 24-29-00659).

Structure of the detonation front of triaminotrinitrobenzene

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The structure of the detonation front (pressure and density distribution) is measured by various methods. The most common are laser methods, which have good time resolution. Each method has its pros and cons. Despite the variety of methods, measuring the structure of the front remains a difficult task.
A DIMEX detector with a spatial resolution of 0.1 mm is used to measure the density distribution using synchrotron radiation at the Extreme State of Matter station. However, the measurement accuracy is limited by the curvature of the front. To measure the sphericity of the detonation front, a 1D detector oriented transversely to the movement of the front can be used with a time resolution of no more than 25 ns, which is possible on a SKIF.
The proposed method uses a photoregistrator to measure the shape of the detonation front in the photoregulation mode. Knowing the shape of the front (assuming cylindrical symmetry), it can be divided into 0.1 mm layers and the X-ray shadow can be calculated on the DIMEX detector. By comparing the measured data with the calculated data, the density of the explosion products is restored.

Modeling of elastic-plastic deformation and “hydrocode” for anisotropic materials and auxetics

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The paper presents a mathematical model that takes into account the anisotropy of elastic properties of materials when determining the cold and thermal parts of the equation of state. Taking into account the anisotropy of elastic properties in anisotropic materials is especially important when modeling dynamic, pulsed loading, since under conditions of intense loading the type of equation of state used determines the process of destruction of the material, as well as the deformation of the destroyed material under compression conditions. The proposed mathematical model, implemented within the framework of the dynamic finite element method, takes into account the anisotropy of elastic characteristics and the anisotropy of the propagation velocities of elastic waves, the anisotropy of the characteristics of the cold and thermal parts of the equation of state, and the anisotropy of the propagation velocities of plastic waves. This is especially important when studying the elastic, plastic and strength properties of single crystals and the processes of deformation and destruction of metamaterials, which are characterized not only by the anisotropy of elastic properties, but also by auxeticity. Examples of calculations in a three-dimensional formulation are given, made taking into account the anisotropy of the cold and thermal parts of the equation of state and without it.

Study of quasi-isentropic compressibility of xenon to a density of 17 g/cm^3 with recording by pulse protonography

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The article presents the results of an experiment on studying the quasi-isentropic compressibility of xenon to a density of 17 g/cm^3, performed on a protonographic complex based on the U-70 synchrotron. In the experiment, ten consecutive proton images of the compression process of gaseous xenon at an initial pressure of 20.36 bar in a small-sized spherical single-cascade explosive device were obtained. Based on the obtained images, the equivalent radii of the first converging shock wave position in xenon, the positions of the inner and outer boundaries of the compressive steel shell, and the position of the shock wave reflected from the center in the material of the compressive shell were determined. The average density of xenon was determined, which at the moment of maximum compression was $\rho_{max} = (17.3 \pm 1.1)$ g/cm^3. One-dimensional and two-dimensional computational modeling of the experiment was carried out, based on which the pressure realized in the experiment in the state of maximum compression was estimated P = (770 ± 40) GPa and for several moments after during isentropic expansion from it.
The study was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No.3 ”Gas Dynamics and Explosion Physics” under State Contract N.4ts.241.4D.23.1085.

Laser-optical methods for registration object parameters under shock loading

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The report presents the latest developments of the Dukhov Automatics Research Institute in the field of laser-optical systems and instruments for the initiation of ultrafast processes and investigation of object parameters under shock loading in gas-dynamic experiments. The main characteristics of unique multichannel interferometric systems designed to record the velocity (PDV) and surface coordinates (LIDAR) of fast-moving objects with ultrahigh temporal resolution are given. The digital cameras with rotating mirror for streak registration or multi-frame recording with nanosecond temporal resolution of fast processes accompanied by optical radiation is presented. The developed sub-nanosecond high-power solid-state lasers with diode pumping for shadow registration of fast-moving objects and investigations of plasma dynamics are demonstrated.

Numerical simulation of combustion and detonation of dust particle-air cloud

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Solid particles and gas mixtures are encountered in many scientific and industrial fields such as combustion, pollutant dispersion, filter technology, ventilation systems or fluid catalytic crackers. Reactive gas-particle interaction is also a key process nowadays in the field of Renewable Energies. In certain fields like agricultural, chemical, metallurgical or nuclear industry (including thermonuclear fusion), special interest has been paid to these mixtures due to safety reasons. The analysis of accident scenarios in the ITER Fusion facility such as loss of coolant accidents (LOCA) or loss of vacuum accidents (LOVA) is of primary importance in order to evaluate pressure and temperature loads generated by a potential dust explosion or detonation. Modeling of dust combustion and detonation processes in a gas mixture using computational fluid dynamics (CFD) and, in particular, the approach used in the CABARET code requires the development and implementation in the code of a number of physical models of various phenomena observed during dust combustion and detonation (namely, chemical kinetics of dust, particle resistance, heat exchange with gas and dust gravity). A modified model of hybrid combustion of carbon, tungsten and aluminium dust adapted for the CABARET code is presented. Thermodynamic properties of the substances under consideration, including tungsten, molecular transfer coefficients and expressions for the rate of surface oxidation reactions of the tungsten dust fraction are given. A model of detonation of carbon and aluminium gas-dust mixture in the limit of fast chemical transformations is presented, with different models of chemical kinetics for carbon and aluminium.

Effect of dimethyl ether on soot formation in acetylene/air flame

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Soot, as a by-product of the combustion of hydrocarbon fuels, has a negative impact on both climate and human health. The addition of dimethyl ether (DME), as an alternative fuel, to the flame is of interest in terms of mitigation of soot yield. In this study, we investigated soot formation in a standard premixed acetylene/air flame with the addition of 0, 5.8 and 15.4% DME. The soot volume fraction, optical band gap and dispersion coefficient were measured using the laser extinction method at wavelengths of 405, 633, 780 and 850 nm. The flame temperature versus height above the burner was measured using thermocouples of types 'B' and 'K'. The average particle size at the height above burner of 19 mm was measured from the analysis of transmission electron microscopy (TEM) images for different fuel mixtures. Kinetic modeling of soot particles was also carried out based on the kinetic mechanisms developed by the CRECK group.

It has been shown that the addition of 5.8% DME has no significant effect on the soot formation process in an acetylene/air flame, while the addition of 15.4% DME leads to a decrease in the concentration of soot particles and a reduction in the average particle size. At the same time, the decrease in the average particle size is accompanied by a decrease in the absorption of the soot particles and an increase in the optical band gap.

This study was funded by Russian Science Foundation, project 23-19-00407.

Results of numerical modeling of quasi-isentropic compression of xenon to a density of 17 g/cm^3 with registration by pulsed protonography.

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Numerical modeling of xenon compression in a small-sized spherical device developed at RFNC-VNIIEF was performed. The shape of the compressed gas was compared with images obtained using pulse protonography. The calculated maximum pressure of xenon, corresponding to the experimentally recorded density $\rho = 17.3 \pm 1.1$ g/cm^3, was $P = 770 \pm 40$ GPa.

Study of detonation excitation and propagation processes in a TATB-based explosive composition in case of shock-wave initiation by low-intensity flat shock waves

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The paper presents the results of a study of shock-wave compression in a TATB-based explosive composition in case of shock-wave initiation by low-intensity flat shock waves with an amplitude 8 GPa. A 100 mm caliber powder loading unit was used to load the sample of explosive in the experiments. The manganin sensor method was used to record pressure profiles. The method of continuous non-disturbing microwave diagnostics was used to record the process of propagation of the initiating shock and detonation waves. the velocity of the free surface of the screen was determined using the PDV-method. Based on the obtained experimental information, the equation of state of a non-reacting explosive composition and the detonation kinetics model MK (Morozova-Karpenko) were validated.

Hugoniot of the uranium alpha-phase in decaying shock wave

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Uranium and uranium-molybdenum alloy (1.4 percent Mo) compressibility was experimentally studied in explosively-initiated decaying shock wave. Stepped samples were suggested to obtain several Hugoniot points in each experiment. PDV was used for process recording [1,2]. The Hugoniot curve for uranium was plotted within the pressure range 10 to 60 GPa corresponding to the alpha-phase. The experimental data were compared with the discrete measurement results [3].

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Study of soot formation process during hydrocarbons combustion by the 2D-LII method

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The process of soot formation during combustion and pyrolysis of hydrocarbons is an important phenomenon associated with a number of practical applications, human health and climate changes. In addition, reliable information about the properties and morphology of soot particles is important for calculating heat and mass transfer in combustion chambers, boilers and other reactors.

One of the useful methods in this field is the well-known and widely used laser-induced incandescence (LII) method. Two-dimensional laser-induced incandescence (2D-LII) and time-resolved laser-induced incandescence (TiRe-LII) methods are the promising laser-optical methods for studying the soot formation along the flame height. In this study the results of 2D-LII and TiRE-LII methods implementation for the investigation of the early stages of the soot particles formation and growth during the hydrocarbons combustion are presented.

The laminar flat premixed ethylene-, and acetylene-air flames with the addition of 0-30

As a result of the conducted research, spatially and time resolved flame particles incandescence signals using 2D-LII and TiRe-LII methods were registered. The profiles of the volume fraction and particle sizes of the studied particles from the obtained ICCD images of the flame using a LII mathematical model and attenuation of the incandescence signals have been extracted.

This study was funded by RSF, project No. 23-19-00407.

Modeling and analysis of flammable hydrocarbon outflows in case of emergency spills, bubbling and vaporization of liquid fuels

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A diagnostic complex for flammable gas droplet emissions of liquid fuels and liquefied natural gas vapors has been created, including aerosol and steam aspirators with brushless gas turbines, infrared gas analyzers, laser multichannel droplet analyzers and capacitive precipitation sensors with digital data transmission to a secure server via an RS–485 communication interface via cable or radio channel.

The above-mentioned complex investigated the outflow of fuels into the atmosphere with crushing of liquid fragments at $\mathrm{Re} < 10^5$ and $\mathrm{We} < 10^4$. When modeling accidents during large-scale LNG spills on the water surface and soil, the rate of its evaporation and droplet emissions into the atmosphere in the mode of film, transient and bubble boiling of LNG were determined by heat exchange between liquids and the atmosphere. The analysis of vapors and droplets under various modes of bubbling oil, fuel oil, kerosene, lubricating oils, water and liquid nitrogen was carried out.

The work was carried out on the topic of "Development of physical and technical foundations of methods for measuring the parameters of aerosol and vapor-gas clouds that occur during large-scale accidents at fuel and energy facilities and the creation of experimental samples of aerosol cloud diagnostics systems" according to NRC Kurchatov Institute Order.

Relief formation on copper polycrystal by laser thermal cycling

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Cyclic exposure to laser pulses with fluences below the melting threshold leads to formation of a relief on the metal surfaces [1]. The danger of this phenomenon lies in the deterioration of optical characteristics of metal mirrors used in high-power lasers [2]. Molecular dynamics simulation allows us to elucidate that the different elastic-plastic response of crystalline grains is responsible for the growth of relief. It is found that the shear stresses required for plasticity are generated by anisotropic thermal expansion of neighbor grains having different lattice orientations. The effective yield strength of material increases after each heating-cooling cycle due to irreversible plastic deformations in a subsurface layer, and thus the relief growth stops after several cycles.

[1] Malinskiy T, Mikolutskiy S, Rogalin V and et al 2020 *Tech. Phys. Lett.* **46** 831–834
[2] Kaplunov I and Rogalin V 2013 *Izvestiya Sochi State University* 120–127

Generator for simulating the combined action of thermal shock and mechanical pressure pulse

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The combined thermal and mechanical action of radiation and particle fluxes poses an increased hazard to the thin-walled structures of modern aircraft [1]. A new method for modeling the complex thermal and mechanical effect of radiation on structures is proposed. Thermal shock is created by surface heating during combustion of the pyrotechnic composition. A mechanical pressure pulse is generated by detonating the explosive.

The developed small-scale thermomechanical generator fundamentally expands the possibilities for making strength tests [2] on the action of radiation and particle fluxes. Pulse heating (up to 200°C) in combination with multiple (up to three pulses) mechanical pressure pulses (50 … 500 Pa × s) are realized using the proposed device.

The generator is made in a mobile version and has passed experimental testing with various requirements for the reproduction of complex loading. Experimental studies have shown the need to take into account the effects of the joint thermal and mechanical effects of radiation on thin-walled structural elements.

[1] Bakulin V and Ostrik A 2015 *Complex action of radiations and particles on the thin-walled constructions having heterogeneous coverings* (Moscow: Fizmatlit)

[2] Ostrik A, Cheprunov A and et al 2008 *Mechanical X-ray action on thin walled composite constructions* (Moscow: FIZMATLIT)

Computational and experimental studies of the dusting process of liquid lead under the action of a sequence of shock waves

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To study the process of two-stage dust formation of lead in 2022, 2023, experiments were conducted using X-ray equipment, a protonographic complex and the PDV technique with a LiF screen. The primary impact was carried out by an unsteady shock wave with an amplitude of about 42 GPa with a decreasing pressure gradient behind the shock wave front with the transition of lead to a liquid state. The reloading was carried out after about 2.3 microseconds by a compacting shock wave with an increase in the pressure amplitude of about 5 GPa. Based on the experimental results, it was possible to visualize the process of secondary dust formation of lead and to plot the velocity distributions of the secondary ejected mass after repeated exposure of the shock wave to the surface of the material. Numerical simulation of shock wave loading and the process of lead dust formation using surface data obtained by an optical profilometer has been performed in the EGAC software package. The calculations describe the experimental results.

Investigation of the high temperature kinetics of dimethoxymethane interaction with O_2 and N_2O

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Dimethoxymethane (DMM, methylal, $CH_3OCH_2OCH_3$) is the first representative of the polyoxymethylene dimethyl ethers (OME_n), which can be used as promising diesel fuel additives. Despite its high potential, there is some lack of data about DMM combustion, especially about concentrations of intermediates and oxidation at high temperatures. Hence, this work is aimed at comprehensive study of the kinetics of high temperature dimethoxymethane oxidation. An experimental part was carried out behind reflected shock waves on a high vacuum kinetic shock tube in highly argon diluted mixtures via the precise method of the atomic resonance absorption spectrometry (ARAS) in the vacuum-UV region of the spectrum at the resonant line of an oxygen atom at 130.5 nm. O_2 and N_2O were chosen as an oxidizing agents to study both molecular and atomic oxygen channels of primary interaction with the fuel. Overall experimental conditions implemented in this work are temperature range from 1800 to 3200 K, pressures 2-3 bar, mixtures of 10 ppm DMM + 10 ppm N_2O and 10 ppm DMM + 20 ppm O_2 in Ar. Time resolved absorption profiles of oxygen atoms obtained in the experiment, then, were modified into the corresponding concentration profiles. The collected data were used to validate current kinetic models. For this purpose, numerical modeling of experimental profiles was carried out in CHEMKIN software using the latest schemes. Calculated and experimental profiles show a good agreement for the mixture DMM + N_2O, meanwhile oxidation by O_2 are described with a great discrepancy between all models.

Laser altimetry and photogrammetry of impact craters based on circumlunar orbital observations

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Measurements on the lunar surface have been carried out for a long time. Started by Galileo back in 1610, they make up a unique series of observations lasting 415 years! Lunar craters and mountains turned out the first elements of the lunar relief to be included in the measurements composition. Today, measurements on the Moon have become purely practical, as spacecrafts are now flying to the Moon, satellites and stations are orbiting the Moon, and "automatic geologists" are digging on the Moon itself in search of the richest mineral deposits. The achieved results make a strong impression. However, some issues of accurate measurements on the Moon and its surroundings remain unresolved. Such issues include orbital photogrammetric and laser altimetric measurements on the Moon. In particular, we are talking about such tasks as the spacecraft's coordinate reference to the lunar coordinate system, the topography and state of matter of impact craters, navigation on the Moon and its surroundings, soft landing, and others. Some researchers set more ambitious goals. For example, lunar craters, seas, and mascons are considered as a natural laboratory for studying the physics of extreme states of matter. Using specific examples, the report examines high-precision measurements on the Moon, the problems that arise and some prospects for their solution. Examples are included: Maunder crater in the Orientale Mare, volcano and ring in Tsiolkovsky crater, secondary impact craters in the "bulbous fields" of the Aitken main crater.

Numerical simulation of detonation propagation using the model of the Morozov–Karpenko kinetics in compositions based on conventional and nanostructured RDX

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Model experiments have been conducted to study the propagation of detonation in channels with a small cross-section loaded with nanostructured RDX (hexogen), obtained using the electron-optical complex NANOGATE 2000 , which is based on a high-speed camera NANOGATE 22 with a shooting frequency of up to 109 fps, used to validate computational methods of the detonation wave propagation process. Numerical modeling of detonation propagation in small cross-section channels for compositions based on conventional and nanostructured RDX has shown that it is possible to take into account changes in the detonation capacity of the composition using the model of the MK (Morozov–Karpenko) kinetics.

Changing the sensitivity of an explosive by modifying the structure of the charge

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The study of the sensitivity of explosives and the methods of changing it is an urgent task of explosion physics. As is well known, with an increase in the number of inhomogeneities, for example, when grinding grains of explosives, the sensitivity can change significantly, and the nature of the change can even be non-monotonic. Thus, for explosives based on hexogen, an increase in shock-wave sensitivity is first observed during grinding, and with a further decrease in the grain size, a decrease [1]. The greatest susceptibility to changes in structure is observed for TNT. In this paper, the effect of carbon single-wall nanotubes added to a TNT charge on the characteristics during detonation is investigated. The study was supported by a grant from the Russian Science Foundation No. 25-29-00042, https://rscf.ru/project/25-29-00042/.

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PDV Interferometer with frequency-and time-division multiplexing.

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The PDV [1] diagnostic systems are widely used in the leading laboratories of many countries to study fast processes of the high energy density physics. The RFNC-VNIITF Gas dynamics Department is no exception. Since these systems require the use of broadband digital technology, they are quite expensive [2]. Once of the ways to reduce the unit cost of the registration channel is to make better use of the functional capabilities of the recorder, i.e. the digital oscilloscope. This is achieved by frequency-and time-division multiplexing of data signals. The paper describes the systems we have implemented using this method, as well as the results of its trial operation and possible areas for further improvement.

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Dynamics and hydrodynamic features of high-frequency corona discharge in methane-air mixtures

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High-frequency corona discharge fed by sinusoidal voltages at frequencies from 1 MHz is currently considered as a promising method for igniting lean fuel mixtures. The interest is primarily due to a significant increase in the volume of gas processed by the discharge compared to classical spark ignition systems. In addition, chemically active particles are effectively produced during discharge operation, which contributes to fuel conversion.

This work studies the effect of gas pressure and composition on the electrical characteristics and structure of the discharge. It is shown that with increasing pressure, a significant decrease in the discharge length and energy input to it is observed. In addition, at pressures less than 3 atm, the discharge has a complex morphology with branching of discharge filaments. It is shown that the discharge filament creates a thermal cavity, the dimensions of which in the first 200 μs approximately coincide with the discharge glow region. Thermal inhomogeneity disintegrates under the action of hydrodynamic instability, which leads to dissipation of the hot region in about 15 ms. It is shown that CH_4 in low concentrations do not affect the structure and dynamics of the thermal trace from the discharge filament. At higher CH_4 contents, local ignition centers are formed, which leads to an increase in the size and lifetime of the thermal cavity.

The work was supported by the Russian Science Foundation within the framework of scientific project No. 24-29-00791.

The dynamics of switching to the mode of high-enthalpy flow generators

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The development of high-speed aircraft and power plants requires extensive testing on ground-based high-enthalpy stands, using generators of high-enthalpy quasi-air flows (GWPs) to simulate flight conditions. All the most powerful wind farms in the countries that occupy leading positions in the field of high-speed aircraft and power plants (SU) development use fire-type GWPs. They create a high-temperature quasi-air flow by burning some kind of fuel in the combustion chamber with compensation of burnt oxygen to reproduce its mass or volume content corresponding to atmospheric air. During the start-up of a fire-type GWP, a delay occurs before its parameters (pressure, temperature, flow rate) reach the preset mode, which is undesirable as it consumes resources and affects the facility, making it crucial to minimize this transition time. To do this, it is necessary to determine the factors influencing the dynamics of the launch and the exit time. In this paper, experimental data on the launches of various GWP wind farms are considered and the factors influencing the dynamics and time of the entry of GWP into operation are analyzed. A mathematical model (MM) for describing the dynamics of the GWP behavior during startup is proposed. Based on MM, it is shown that the main factors determining the dynamics of the GWP output to the mode are the volumes of pipelines through which the components are supplied, the combustion chambers of the GWP, the ignition time of the combustion chamber of the GWP and the diameter of the critical section of the aerodynamic nozzle of the stand. The calculated data obtained on the basis of the developed MM are compared with the results of experimental studies.

Shock tube study of the kinetics of ammonia pyrolysis at high Ar dilution conditions by the method of absorption spectrometry

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Ammonia is widely used in industry, has a developed production infrastructure and is relatively close in physical properties to liquefied natural gas, which is frequently used as a fuel. In recent years, ammonia has also attracted much attention as a carbon-free fuel and an excellent chemical carrier of hydrogen, solving issues related to the safety of its storage and transportation. However, the problem of low reactivity and the formation of NO_x oxides during combustion of ammonia, has not yet been finally solved. In this regard, the study of the fundamental aspects of pyrolysis and combustion of NH_3 remains an actual task. This work is aimed at clarifying the kinetics of high-temperature pyrolysis of ammonia. The experiments were carried out in a shock tube behind reflected shock waves and covered the range of 2000–3300 K at a pressure of 2–3 bar. To study the decomposition reactions of ammonia, highly diluted mixtures were used (700–3000 ppm NH_3 in Ar). Registration of NH_3 absorption profiles was first realized by the method of absorption spectrometry at a wavelength of 130.5 nm. To transform the obtained data into concentration profiles of NH_3, its absorption cross-section at 130.5 nm was also measured for the first time. Thus, the implemented experimental technique allowed not only to measure the kinetics of NH_3 pyrolysis, but also directly took into account adsorption of ammonia on the walls of the shock tube, that is extremely important when working with highly diluted ammonia-containing mixtures. This work was supported by RSCF grant No.24-19-00165.

On the effect of gaps on two-layer plate acceleration dynamics

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Any compound item has irremovable gaps between its components. The gaps come from fabrication technology, non-perfect fit in assembling, or the different thermal expansion of materials. The gap size influences the velocity of shells and the pressure in them when they are accelerated by a shock wave. The paper presents results obtained in the study on how the gap size influences the final velocity of a two-layer steel plate accelerated by a shock wave. The layers were 1 mm thick. The gap between them was varied from 0 to 0.2 mm. To avoid the early effect of the overtaking unloading, the plate was loaded by a 6-mm-thick aluminum projectile accelerated to a velocity of about 680 m/s on a light-gas ballistic plant. The free surface velocity measurements were taken with a multi-channel laser-heterodyne technique (PDV) [1-2]. In the course of the work we have studied the effect of the size of the gap between plates on their peak and final velocities, and on the pressure near the probed surface when the first shock comes. We also implemented shock-wave interference on the plate contact surface for a certain gap size.

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Peculiarities of Soot Formation During Ethylene Pyrolysis

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Numerical methods are being actively developed to make it possible to predict soot formation under various conditions. Experimental data obtained during hydrocarbons pyrolysis in shock tube serves as a useful data for the combustion kinetic mechanisms validation at high temperatures. In this study, the features of soot formation at various pressures (6-26 bar) and carbon concentrations of 2.8-3.8 mol/m^3 during ethylene pyrolysis have been experimentally and numerically investigated. The diagnosis of the soot formation was carried out using the laser extinction method at 633 nm.
It have been shown by kinetic calculations that a significant drop in the mixture temperature, which determined by the initial pyrolysis reactions, varies at different pressures. At low pressures (above 6 bar) the soot yield maximum shifts to a high temperatures region. The pressure effect on the soot yield magnitude during ethylene pyrolysis was observed only in [1] at pressures above 25 bar; in this study the soot yield dependence on pressure in the investigated range of 6-26 bar was not observed. Kinetic modeling shows that the ethylene decomposition channels are independent of pressure. Thus, the reasons for the change in the temperature drop magnitude at different pressures observed in experiments most likely consists in changing of the kinetics of the initial stage of ethylene pyrolysis.
This study was funded by Russian Science Foundation, project 23-19-00407.

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The LIF diagnostics of PAH and NOC during hydrocarbons pyrolysis behind shock wave

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The soot is an undesired product of incomplete combustion and pyrolysis of hydrocarbons. The main precursors of soot are considered to be polycyclic aromatic hydrocarbons (PAH). Both the soot and its precursors have negative effects on human health and environment. Further investigations of the chemical processes involved in soot formation are needed to reduce soot emission. Laser-induced fluorescence (LIF) method is one of the promising tools for studying complex chemistry of soot formation. Temporal LIF signals can give the information on the mixture composition, with LIF it is possible to detect nano-organic carbon (ultra-fine particles up to 5 nm in size). Spectral LIF give the information on growth of the soot precursors. This work was focused on obtaining temporal and spectral LIF signals from acetylene mixture pyrolysis. Emission of the mixture was induced by 75 ps laser pulse on the wavelength of 266 nm. Then emission of the mixture was focused on the PMT and on the slit of the spectrometer simultaneously. With PMT temporal signals were obtained. The spectral composition of the mixture's radiation was recorded by a spectrometer combined with an ICCD camera. In present study time-resolved LIF signals as well as spectra records were obtained from reacting mixture of pyrolyzed acetylene. The temporal signals showed the presence of nano-organic carbon (NOC) in mixture. Spectral signals were composed of thermal emission from particles and fluorescence of PAHs and NOC. Influence of the temperature and pressure on recorded spectra are discussed. This study was funded by Russian Science Foundation, project 23-19-00407.

Nanoscale engineering of oscillating systems in reaction zones: towards smart energetic materials

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This research introduces a transformative approach to energetic materials (EMs) through the manipulation of self-organizing nanostructures within reaction zones. By engineering dynamic "burning cells" and energy-driven patterns that emerge from the interplay of chemical reactions and phonon-mediated energy transfer, we achieve unprecedented control over combustion behavior. These nanostructures self-synchronize into collective networks that function as programmable energy exchange channels, fundamentally altering the bulk properties of reaction zones. Our approach integrates multiple control mechanisms, including ultrasound fields, carbyne-enriched energetic antennas for microwave control, plasma-acoustic coupling, and electromagnetic field manipulation. Using 3D printing technology, we fabricate hierarchically structured energetic materials with electromagnetically tuned responses, incorporating reactive antenna structures that enable on-command switching of the burning surface. This advancement addresses the traditional limitations of EMs in active burning rate control, offering precise manipulation of energy transfer pathways and reaction kinetics at the nanoscale. When phonon wavelengths match the characteristic dimensions of microstructures, resonance phenomena create standing wave patterns that drive self-organization into synchronized networks, enabling real-time modification of combustion behavior and energy output. The technology enables tailored energy release profiles for applications ranging from microsatellite thrusters to deep-space propulsion systems.

Surface modification by nanosecond duration laser as the way of enhancement very high cycle fatigue resistance of metal alloys

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The surface of Ti–6Al–4V alloy samples was treaded by an ytterbium nanosecond pulsed fiber laser manufactured by IPG Photonics, with an emission wavelength of 1064 nm. The irradiation parameters were as follows: pulse duration of 200 ns, pulse energy of 1 mJ, and a spot diameter of the laser beam focused on the surface of approximately 30 microns. Laser processing was conducted beneath a layer of water approximately 2 mm thick. The Very High Cycle tests were carried out on a Shimadzu USF-2000 ultrasonic fatigue machine at 20 kHz with air cooling.
The results obtained indicate the changing of thin subsurface structure. The method developed by the authors allowed to separate the influence of surface quality (roughness) and laser treatment on fatigue properties of Ti–6Al–4V alloy. The processing variant proposed by the authors demonstrates improvement of characteristics by 9-11 percent under conditions of Very High Cycle tests and is a promising method of increasing fatigue resources of aircraft engine building materials.
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).

Determination of detonation initiation threshold in emulsion explosives at different concentrations of microspheres

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The object of the study in the work is a reverse emulsion based on an aqueous solution of ammonium nitrate with different concentrations of hollow glass microspheres. The average diameter of the microspheres is 70 μm. The authors studied three types of emulsion matrix samples featuring various filler concentrations, the latter being 1, 3 or 4% by mass. The mass velocity profiles were recorded with VISAR laser Doppler interferometer.

The initiation thresholds for all the studied compositions under shock-wave loading were determined.

At pressures above the reaction initiation threshold, the evolution of the wave profiles as they propagated through the sample was recorded. This made it possible to determine the distance to the steady-state detonation regime depending on the amplitude of the incoming wave. For example, for a composition with 1% microspheres, the steady-state detonation regime is established at a sample thickness of 15 mm at a pressure of 3.82 GPa. Increasing the microsphere concentration to 3% increases the sensitivity of the emulsion explosive, which leads to the establishment of a steady-state regime at the same sample thickness at a lower pressure of 1.34 GPa.

The structure of the wave profiles corresponds to the classical detonation wave ZND with a characteristic time in the reaction zone not exceeding 1 μs.

The work was completed according to the State assignment, registration number 124020600049-8.

Tomography of silicified graphite samples under ballistic and dynamic loading

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The study aims to investigate the properties of silicified graphite under ballistic and dynamic loading. Data were obtained using photonic Doppler velocimetry (PDV) with advanced digital signal processing techniques [1]. Ballistic loading was performed using a ballistic setup [2]. The second type of dynamic testing is dynamic indentAtion on a Hopkinson of Kolsky. The velocity profile during ballistic loading was reconstructed from PDV signals using wavelet and chirplet transformations to isolate low-frequency modes. These modes were further used to validate material failure models, particularly for brittle materials such as ceramics. Post-test X-ray computed tomography (CT) of silicified graphite samples revealed damage patterns after ballistic and dynamic loading. Ballistic loading caused localized damage, including radial cracking and spallation, while dynamic loading led to distributed microcracking and delamination. These findings provide valuable insights into failure mechanisms and help improve material models for predicting performance under extreme conditions.

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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Three-dimensional recording of parameters of a shock-loaded surface and dispersed phase in gas-dynamic studies

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The report presents research and developments in the field of three-dimensional registration of deformable loaded surfaces and particles of the dispersed phase generated during the impact destruction of materials in gas-dynamic experiments. The results of experimental studies are described using methods such as parallax stereography, structured light, and digital dynamic holography. The application of these methods for various setups of gas-dynamic experiments has been developed. The capabilities and limitations of these methods are demonstrated, and options for their integration and joint use with other optical methods - laser heterodyne interferometry and broadband laser ranging - are explored.

Investigation of elastic-plastic wave propagation during laser shock peening by PDV data

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This work studies the elastic-plastic wave propagation in metals as a result of laser shock peening. Laser shock peening (LSP) is used to improve the strength, corrosion resistance and fatigue failure resistance of materials and structures. The essence of the technique is the formation of a residual stress, which prevents the initiation and propagation of fracture. A powerful laser pulse interacts with matter and generates plasma, which expands hydrodynamically and creates an elastic-plastic wave. The aim of this work is to establish the elastic-plastic wave velocity, magnitude and shape of the pressure pulse at different power densities of laser pulse and to correlate the obtained data with the magnitude and depth of the resulting residual stress field. The study was carry out on metal specimens. The elastic-plastic wave velocity profile was recorded using a photonic Doppler velocimeter (PDV) at different laser power densities (3 — 30 GW/cm^2). Measurements are carried out under near-process conditions, allowing optimisation of the treatment process for the benefit of specific qualified customers. As a result, the pressures applied to the material and the pulse shapes of elastic-plastic waves generated by laser shock with different power densities were obtained. These data were used as boundary condition in the numerical solution of the problem for determining the residual stresses in the material. 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).

Initiation of quasi-plastic shear in liquids as a method of micro-explosive spraying of fuel

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Initiation of micro-explosive spraying of fuel is considered in the links with hydro- and sonoluminescence during the flow of hydraulic oil in a narrow channel using an original experimental setup [1]. The assumptions are substantiated that liquids can exhibit mechanisms of quasi-plastic momentum transfer at strain rates $\dot{\varepsilon} > 10^5$ s^{-1}. One of the manifestations of localized shear in liquids at strain rates $\dot{\varepsilon} \sim 10^5$ s^{-1} is the hydroluminescence effect in the near-wall region flowing in the channel. It has been experimentally established that there is a threshold value of the strain rate at the Reynolds number Re $\sim$ 1350 (∇P $\sim$ 1.2 GPa/m) when a sharp increase in the intensity of hydro- and sonoluminescence signals is observed.

The obtained experimental results made it possible to propose a method for initiating secondary fuel spraying by a microexplosion at the appropriate topology of hydroluminescence pattern. When fuel passes through a narrow nozzle channel at strain rate $\dot{\varepsilon} > 10^5$ s^{-1}, a pseudoplastic momentum transfer mechanism is realized with pronounced hydroluminescence effect. When the fuel leaves the nozzle into the combustion chamber, due to the pressure drop, cavitation bubbles (microexplosions) are intensively formed due to shear activation of hydroluminescence centers. Explosive spraying of droplets enhances local mixing of fuel with air in the combustion zone, which leads to more complete and efficient combustion.

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 April 23, 2024).

[1] Efremov D, Uvarov S, Dezhkunov N and Naimark O 2024 *Factory laboratory. Diagnostics of materials* **90** 36–41

Investigation of the initiability of low-sensitivity plastisol-type explosives

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The paper presents studies of the initiability and detonation ability of low-sensitivity explosive compositions of the plastisol type. The influence of a number of parameters on these characteristics is considered.

Determination of the critical detonation thickness of thermoplastic explosives

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The paper presents the results of studies of the critical detonation thickness using non-disturbing diagnostic methods. The influence of various factors on this parameter is considered.

Study of early stage of soot formation in a flat laminar ethylene/air flame by mass spectroscopic method

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Soot particles, when released into the atmosphere, have a negative impact on the Earth's climate and human health. The formation and growth of soot particles are complex phenomena that include many physical and chemical processes. The early stages of soot formation are of the greatest interest: the formation of a first aromatic ring, the growth of polyaromatic hydrocarbons, and the transition from gas-phase components to the condensed phase. To study these processes in detail, the experimental measurements in standard McKenna burner by a quadrupole mass spectrometer have been developed. A sampling system was designed, by which the components of the flame, entering the sampler, are diluted in an overwhelming amount of nitrogen and stop chemical interactions. The intensities of the mass peaks of the flame components at different heights above the burner in the range from 0 to 300 a.m.u. were determined. Additionally, the results of kinetic modeling using the CRECK mechanism in the Cantera program are presented. This study was funded by the Russian Science Foundation, project No. 23-19-00407.

Mechanisms of accelerated flame propagation in channels

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The article presents the results of a computational and theoretical study of the mechanisms responsible for the acceleration of a gaseous mixture flame in a channel, using the example of mixtures of stoichiometric mixtures of acetylene with oxygen diluted with nitrogen. The modeling was carried out using the non-dissipative "CABARET" method [1] and the reduced scheme of chemical kinetics [2]. Based on detailed numerical modeling in an axisymmetric formulation, the difference in the flame dynamics of mixtures with different proportions of inert diluent is shown. It is established that the presence of an accelerated stage of flame evolution preceding the transition to detonation is consistent with the formation of a vortex flow on the scale of the boundary layer. Analysis of the stability of the boundary layer ahead of the flame front [3], carried out in accordance with linear stability theory, showed that, depending on the activity of the mixture, it is possible to observe both a stable and an unstable scenario of boundary layer evolution. Based on this analysis, a technique was formulated that could be used to determine the critical values of the system parameters that separate one flow evolution regime from another.

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[2] Varatharajan B N and Williams F A 2001 *Combust. Flame* **124**(4) 624–645

[3] Yarkov A V, Kiverin A D and Yakovenko I S 2024 *J. Eng. Phys. Thermophys.* **97** 1751–1759

Experimental study of powdered and solid andesite properties at low impact loading conditions

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The shock properties of the lunar regolith analog are studied by the VISAR laser interferometry in the range of impact velocities from 250 to 800 m/s. The samples are made of powdered and solid andesite. Two types of powdered andesite are studied: (i) with particle sizes from 10 to 200 μm, average particle size of 80—90 μm and initial density of 1.34 g/cm^3 and (ii) with particle sizes from several hundred nanometers to 400 μm and initial density of 1.16 g/cm^3. The data obtained covers a region of impact velocities in which no previous studies have been conducted. At a shock compression pressure of 1.9 GPa, the elastic precursor was found in solid andesite. In the particle velocity – shock wave velocity plane, the Hugoniots of powdered andesite lie below the Hugoniot of the solid andesite, which is primarily due to the absorption of impact energy during pore closure. At the same time, the Hugoniot of powdered andesite with narrower particle size distribution and higher bulk density lies above that of powdered andesite of the second type, which is consistent with the known data on porous media.

Moving window technology for simulation of shock wave propagation

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This paper describes an approach to modeling stationary shock waves (SW) in materials using the developed method of moving observation window used in conjunction with Lagrangian numerical methods. This approach allows to iteratively adjust the reference frame to the boundary conditions, which provides control of the entrance to and exit from a fixed computational domain of particles modeling the flow of a compressible medium.

The method was first applied with the molecular dynamics [1] method, and the method developed in this work can also be applied with the smoothed particle hydrodynamics method and with mesh Lagrangian methods of similar purpose. This extends its applicability for modeling a wide range of physical processes, including the dynamics of liquids and gases under various conditions.

The paper shows the advantage of the new method over the previously developed method [2] in terms of the speed of establishment of stationary flow in the observation window.

This work was supported by Russian Science Foundation, grant No. 24- 19-00746.

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[2] Murzov S A, Parshikov A N, D'yachkov S A, Egorova M S, Medin S A and Zhakhovskii V V 2021 *High Temperature* **59** 230–239

Shock-wave dynamics in pressed aluminum V-ALEX nanopowder

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Studies of the impact response of nanostructured systems are of great interest due to their advantageous characteristics provided by the ultrasmall scale of constituent elements. Numerous works investigated high-strain rate processes in various nanomaterials and nanosized bodies to gain a comprehensive understanding of their dynamic properties. In this work the dynamic behavior of the pressed aluminum nanopowder of 30% porosity was studied in plate impact experiments at shock pressures and strain rates up to 2.4 GPa and $4{\cdot}10^7$ s^{-1}, respectively. Samples were made of the commercially available V-ALEX nanopowder. The purpose was to explore the effect of the extremely small size of powder grains (100-200 nm on average) on the shock response of this nanomaterial. Plate impact experiments were carried out using the common gun technique. The two-step structure of propagating shock compaction waves was captured using a laser velocimetry technique. It was shown that the properties of the precursor wave traveling in the material ahead of the main shock compaction wave are controlled by the grain scale. The parameters characterizing the structure of the main wave, maximum strain rate and rise time, are also affected by the grain scale, but the shocked state behind this wave is only governed by the initial porosity, at least in the studied pressure range. Additionally, the influence of pore morphology and initial porosity of aluminum on the longitudinal sound velocity, precursor velocity and Hugoniot elastic limit was described. This work was supported by Russian Science Foundation, grant No. 24-19-00746.

Adiabatic expansion of Lennard–Jones matter into the liquid-gas region

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The purpose of this work is to study a fluid sample expansion into the unstable liquid-gas region under isentropic expansion. To achieve this goal, the LAMMPS code is used. The work exploits a simulation scheme that resembles experiments with shock tubes. The test sample, which is in a high-pressure state, is placed in front of substances (anvils) with a smaller dynamic impedance (normal density times normal sound velocity). After that, the simulation process begins, during which the propagation of a shock wave and a rarefaction wave is observed in the simulation cell. The program allows one record the state of the system at various moments, observe the wave velocities, and calculate all the necessary thermodynamic quantities such as density, temperature, and pressure. It is shown that when low-density barriers are placed, the sample is unloaded to a state corresponding to the position of the two-phase region. However, a homogeneous state does not have time to form. A complex wave flow is realized, which differs from the theoretical concepts following from the solution of the discontinuity problem. In the course of numerical experiments, it was decided to use substances with a low atomic mass to obtain low-density barriers with a high concentration of particles. This change will make it possible to reduce the influence of the porosity of the anvil, as well as to study in more detail the processes occurring at the interface of the sample and anvil. The paper will present the distribution profiles of various quantities in the process of adiabatic expansion and their theoretical analysis, as well as animations of the expansion process. This work was supported by Russian Science Foundation, grant No. 24-19-00746.

Shock-induced ignition of ammonia doped with promoting admixtures

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Ammonia NH_3 is considered a promising hydrogen carrier. Its poor qualities as a pure fuel make it necessary to use various additives as combustion promoters, particularly biofuels whose use is necessary to achieve carbon neutrality. Several detailed kinetic models of ammonia combustion in the presence of hydrocarbons and oxygenates have been developed recently [1], and their validation with experimental data remains an important task. Shock-wave induced ignition of ammonia doped with simplest hydrocarbons CH_4, C_2H_2, C_2H_4 and C_2H_6, as well as oxygenates CH_3OH and CH_3OCH_3, was studied experimentally and temperature dependencies of ignition delay times were obtained in range of temperatures 1250–1950 K and pressures 3.5–13.5 bar. Ignition was observed behind the reflected shock waves in a shock tube of a standard design by registration of OH radical emission. All studied argon-diluted combustible mixtures contained 7 mol. % oxygen and were stoichiometric. Kinetic modeling was performed in Cantera [2] using kinetic mechanisms of interest. Dependencies of induction times on temperature, pressure and mixture composition were obtained and compared with experimental results. A sensitivity analysis of induction times to rate constants of individual reactions was carried out and indicated a notable role of underinvestigated reactions involving N_2H_n species.
This work was supported by RSCF grant No 24–19–00165.

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[2] Goodwin D, Moffat H, Schoegl I, Speth R and Weber B 2023 Cantera: An object-oriented software toolkit for chemical kinetics, thermodynamics, and transport processes Report

Combined action of shock wave heating and laser photolysis on methane-oxygen mixture

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Reactions of atomic oxygen with hydrocarbons play a key role in the initial stages of their interaction and are of great importance in combustion processes. Methane, as the main component of natural gas and the most common hydrocarbon in the atmosphere, is one of the main representatives of this series. Most experimental data on direct measurements of the constant of the reaction of methane with an oxygen atom were obtained at the end of the last century. Only with the help of measurements of atomic resonance absorption spectroscopy (ARAS) in shock waves with extremely low initial concentrations of methane was it possible to isolate the very first stages of the reaction of thermal decomposition of CH_4. The use of laser photolysis in combination with highly sensitive ARAS technology helped to exclude, in principle, speculative analysis of side reactions. In this work the time profiles of the O atom concentration were measured by resonance absorption at a wavelength of 130.5 nm. The kinetics of interaction of oxygen atoms with methane at temperatures of 700–1900 K were studied at the experimental complex "Nefrit" created at the JIHT RAS under the combined effect of shock-wave heating and laser photolysis on a gas mixture of 1000 ppm O_2 + 20 ppm CH_4 in argon. Precise experimental data on the rate constant of the reaction of methane with oxygen atoms were obtained and comparted with the previous studies. Using modern kinetic models of methane combustion, numerical modeling of the formation and consumption of atomic oxygen under the corresponding experimental conditions was carried out.

Mathematical modeling of ignition of high explosives

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The paper presents a mathematical model of the possible appearance of hot spots in a thin layer of explosives due to the operation of the dry friction force. This mode of interaction is realized in the case of an adiabatic shift when the steel impactor slides along the explosive surface. As a result of the friction force, their impactor–explosive contact boundary heats up, and the heat generated at the contact boundary spreads into the material of the impactor and the explosive under study. To determine the proportion of the heat flux propagating into the material under study [1] and the temperature of the contact surface, a combination of an expression is used to calculate the surface temperature of a body under the influence of a given heat flux [2] and the condition for equal temperatures on the contact surface.

The paper shows that the transition from dry friction to viscous friction is possible only when melting a certain final layer of the material under study. In this case, it is possible to heat the explosive surface above the melting point, which may eventually create conditions that lead to ignition of the molten explosive layer.

The conducted test calculations show that the developed mathematical model adequately describes the ignition of explosives due to the operation of the dry friction force and can be used to analyze the appearance of hot spots in a thin explosive layer in the case of adiabatic shear during sliding at low speeds of a steel impactor on the explosive surface.

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[2] Amosov A P 1996 *Journal of Samara State Technical University, Ser. Physical and Mathematical Sciences* **4** 208–235

The pointl nature of the initiation of liquid explosives under shock wave action.

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Currently, one of the main methods of studying the course of detonation processes is the initiation of detonation in a condensed explosives by a shock wave. The study of the phenomenon of the transition of a shock wave into a detonation wave is of great practical and theoretical importance, as it touches on fundamental issues related to the origin and development of detonation in condensed systems. It is known that the process of formation and development of the detonation front of condensed explosives can proceed by two mechanisms: homogeneous and heterogeneous. This paper presents the results of observations in homogeneous mixtures of liquid explosives based on tetranitromethane and bis-(2-fluoro-2,2-dinitroethyl)-a formality (FEFO) with inert diluents of the focal detonation initiation process, which does not correspond to the classical concepts of detonation of such mixtures.

Compression of a solenoid by a converging cylindrical detonation wave

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Magnetic flux compression generators using explosives (explosives) are devices that convert part of the energy contained in explosive explosives into electromagnetic field energy. Due to the high power and high pressure generated by explosives, these devices have found wide application as switching power sources and generation of ultra-high magnetic fields, especially where weight and volume are limited. In this work, using a laboratory installation with a small explosive charge (less than one kilogram), the possibility of axisymmetric compression of a copper solenoid was demonstrated. The use of specially developed multipoint initiation modules made it possible to obtain a smooth converging cylindrical detonation wave. The minimum number of inhomogeneities of such a wave when it reaches the surface of the coil makes it possible to achieve high-quality axisymmetric compression and, as a result, a significant predicted increase of the magnetic flux.

Underground conical shock waves patterns in complex cratering

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The aim of this work is to apply the recently derived patterns of conical shock wave theory to the distribution of the matter flow, energy flow and momentum between high-energy impactors and the surfaces of atmosphere-free planets and planets with a thin atmosphere. Nowadays, it has not yet been possible to record experimentally what the geometry of the internal flow channels is during the distribution of energy, momentum and matter taking place during the ongoing complex cratering process. In addition, the low dynamic from satellite images do not record what is going on underground. However, it is here where Conical Shock Wave Pattern (CSWP) developed from the conical flow theory shed light on the understanding of this dynamic phenomenon with faster dynamic or much shorter duration transition. In consequence, the authors apply recently derived Conical Shock Wave Patterns CSWP to analyze and model the complex distribution of the underground cratering flow.

Modelling of reflected shock bifurcation in a cylindrical channel

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Shock tube is one of the most oftenly used tool for chemical kinetics study. Herewith, gas-dynamic non-uniformities could affect the chemical process significantly, so it is important to understand how exactly such non-uniformities arise and develop. In particular, the interaction of reflected shock wave with a boundary layer is of research interest. This phenomenon was in general explained in the model proposed by Mark [1] and further was studied in numerous experimental works (see e.g. [2]). At the same time, the numerical representation of the phenomenon on the quantitative level is still not reached. In the present work the dynamics and parameters of the reflected shock wave interacting with the boundary layer are studied numerically in argon, in air, and in a hydrogen–nitrogen mixture for Mach numbers M = 1.3–3.5 in a 76-mm-diameter smooth shock tube. Non-slip isothermal boundary conditions were set up on the channel walls.
The calculations show a satisfactory agreement with the experiments [2] in terms of axial projection of the oblique shock wave, axial flow distance and triple-point height.

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3. Equations of State for Matter

Equation of state of matter under extreme conditions

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The report will provide an overview of the progress in research on the equation of state of matter under extreme conditions.
The results of experimental studies under conditions of high static and dynamic pressures, theoretical calculations from first principles (ab initio), and models of equations of state of matter under extreme conditions will be considered.
The main attention is paid to new experimental techniques and progress in first-principles calculation methods.

Anomalous thermodynamics and entropic phase transitions in warm dense matter

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Poorly recognized thermodynamic objects – Anomalous Thermodynamics Regions (ATR) are under discussion as combination of *entropic phase transition* and conjugated region with regular (gapless) but *anomalous* thermodynamics [1]. It is the *forced delocalization* of some kinds of bound complexes (e.g. *pressure ionization*, *pressure dissociation* etc) that is the *main driver* of all physical transformations in both parts of ATR. And it is *multilayered structure* of thermodynamic surfaces $T(P,V)$, $S(P,V)$, $U(P,V)$ (temperature, entropy, energy)—that is the unique *"geometric"* feature of these thermodynamic transformations in both parts of ATR. The main sequence of this multilayered structure of the surfaces $T(P,V)$,$S(P,V)$,$U(P,V)$ is anomalous (*"returnable"*) type of crossing of the ATR-zone by dynamic trajectories of shock and isentropic compression and expansion. The main sequence in turn of such type of crossing is anomalous Z-shaped (*"zigzag"*) form for dynamic PV-trajectories mentioned above. That leads in turn to *violation* within ATR for *global concavity* property for isentropes and hence to possibility of *hydrodynamic instability* of the simple (*single-wave*) form of the shock and isentropic compression and expansion.
Three examples of discussed ATR: - Two entropic Liquid-Liquid phase transitions in high T-P nitrogen and hydrogen, and ATR for Quark-Hadron phase transition in ultra-dence nuclear matter.

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Equation of state for cold matter at high compression ratios

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Interest in the study of the thermodynamic properties of matter in extreme states at high pressures and compression ratios is due to the need to know the equation of state to solve various fundamental and applied problems of high energy density physics. This paper is devoted to a brief review of known models for describing the dependences of the specific internal energy and pressure of a cold (at zero absolute temperature) substance upon the compression ratio (density divided by the density value at zero pressure). The range of compression ratios up to one million is considered. Examples of calculated dependences for different models are given, including the quantum-statistical Thomas–Fermi model with corrections, in comparison with available experimental data at high pressures.

Some characteristics of atoms and ions of superheavy elements

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The extended periodic table of Mendeleev, including atomic numbers of elements up to $Z = 172$, is discussed in the literature [1], [2], moreover, experimental measurements are available only for elements up to Lawrence ($Z = 103$).
The theoretical study of superheavy elements requires taking into account many effects: relativistic, quantum electrodynamics, core size, etc. The Dirac-Hartree-Fock multi-configuration method and other methods are used to predict the electronic configuration, ionization potentials and other characteristics of atoms and ions of elements with atomic numbers $Z > 103$.
On the other hand, there is a quasi-classical method for describing multi-electronic systems, the accuracy of which increases with the number of particles. This was confirmed in the patterns found in the work of the author [3] in the binding energies of atoms and multiply charged ions in the case of hydrogen-like filling of electronic shells.
In this paper, an attempt is made to find quasi-classical patterns in the available computational data for elements with atomic numbers in the range $Z > 103$.

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Modeling of shock wave loading of calcium oxide

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The study of the behavior of oxides in particular calcium oxide under high pressures and temperatures is of great interest in various fields of condensed matter physics, including geophysics [1]. This research presents the results of modeling the shock wave loading of calcium oxide (CaO) up to pressures of 100 GPa, taking into account phase transitions. The sample is considered as a mixture of low-pressure and high-pressure phase's in the field of polymorphic phase transition. The model used for calculations assumes that the components of the material are in thermodynamic equilibrium during shock wave loading [2, 3]. An equation of state for the low-pressure phase B1 is obtained up to 50 GPa with an isothermal modulus of elasticity of $K_0 = 42.8$ GPa and its derivative in pressure 5.6. The equation of state for the high-pressure phase B2 is also obtained at pressures from 50 GPa and above, with parameters 389.9 GPa and 3, respectively. These results are verified using experimental data obtained from dynamic experiments and the calculations of other researchers.

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New non-empirical approximation for the ionic thermal contribution to the equations of state based on average-atom models

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A new simple approximation for the ionic components of thermodynamic functions is proposed, which reflects the main regularities of their behavior with changes in temperature and density, revealed by analyzing the results of calculations by the pseudoatom molecular dynamics method, and can be employed to calculate the ionic thermal contribution to the equations of state based on average-atom models. It is shown that the use of the new approximation for the ionic contribution instead of the ideal gas or one-component plasma ones significantly improves the accuracy of the Liberman model calculations.

Gapped momentum states and critical dynamics of momentum transfer in condensed matter under intensive loading

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Gapped momentum states and critical dynamics of momentum transfer in condensed matter under intensive loading
Critical dynamics and gapped momentum states (GMS) related to the initiation of collective modes of defects are considered as the mechanism of momentum transfer in condensed matter under extreme loading. Generation of collective modes of defects of different complexity was predicted by statistically based thermodynamics of ensembles of typical mesoscopic defects (microshears, microcracks) revealing special type of critical phenomena, the structural scaling transition. GMS are realized due to the excitation of the collective modes of defects (solitary waves and blow-up dissipative structures) with the nature of the self-similar solutions of the evolution equation for the order parameter of condensed matter with defects (defect induced strain). Above collective modes are localized on the set of spatial scales with characteristic temporal dynamics providing defects induced mechanisms of momentum transfer and dissipation. The localized spatial scales are related to the set of scales associated with GMS wave numbers. Critical dynamics of condensed mater under intensive loading and GMS are illustrated by original experimental data in shocked condensed matter (solid and liquid) under the study of self-similar steady shock wave fronts, failure wave dynamics, fragmentation dynamics. 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).

Polymorphic equations of state of silicon dioxide

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Quartz is used in dynamic experiments as a standard material in the impedance matching technique. The impedance matching technique assumes reliable equations of state (EOSs) to describe the shock behavior of the standard material at high pressures. In shock compression, the transition of quartz to dense-packed structural modifications (coesite, and further stishovite) requires noticeable energy consumption, and it is important to consider the polymorphism for construction of the EOS. In this work, polymorphic EOS of crystalline silicon dioxide are built.

Constructed polymorphic EOS are used in the processing of experimental data on the shock compression of periclase (MgO). Explosive cumulative Mach generators were used to produce shock waves in single-crystal SiO_2 and MgO. Shock velocities were determined from shock transit times using fiber-coupled fast optical photodetectors. The impedance matching with quartz standard with constructed EOS were used to define Hugoniot states in MgO. Simultaneously, the brightness temperature of both MgO and SiO_2 was obtained by optical pyrometer. New data on shock Hugoniot of MgO were obtained.

Measurement of thermophysical properties of metals used in nuclear energy through experiments with pulsed electric current heating

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In this work, the dependence of enthalpy, electrical resistivity, and sample volume on temperature was measured for metals such as zirconium, iron, nickel, and hafnium using an established setup for assessing the thermophysical properties of materials via pulsed electric current heating. System is equipped with a high-strength steel cell capable of withstanding pressures up to 7 kbar, using helium as a pressurizing medium. A purposely made pyrometer covers a wide temperature range of 1300—6000 K, with heating rates up to 2×10^8 K/s.
Additionally, for several metals, the change in melting temperature as a function of pressure was measured, enabling estimation of the melting line slope up to 4 kbar. This technique assumes that the emissivity of metals remains constant within this pressure range. Conducting these experiments is challenging due to the stringent stability requirements for the pyrometer and the optical path. A significant factor is the change in the refractive index of the gas, which affects the transmittance at the gas-sapphire boundary. For the metals studied, the variation in the pyrometer signal due to the optical system's transmittance is comparable to the change in radiation brightness as the melting temperature increases. The measured melting line slopes align well with estimates derived from the Clausius-Clapeyron relation and recent ab initio calculations.
The work is supported by the Russian Science Foundation, grant No. 20-79-10398.

Equation-of-state model for rocks as mixtures of minerals at high pressures and temperatures

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In this paper, a model of the equation of state for a multicomponent system as a mixture of individual substances over a wide range of pressures and temperatures is presented. The model assumes that the thermodynamic equilibrium is achieved in the mixture—equality of pressures and temperatures of the components [1]. Knowing the equations of state for the components and their mass fractions, the equation of state for the mixture is determined. This model is used to calculate the thermodynamic properties of minerals and rocks. For example, such rocks as forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$) are presented within the model as mixtures of silicon dioxide (SiO_2) and magnesium oxide (MgO) with corresponding mass fractions of the components. The equations of state for the components (in particular, SiO_2 and MgO) of the studied mixtures are presented. The shock adiabats for the components and mixtures are calculated using the proposed equations of state. The results of these calculations are compared with available experimental data on shock compression at high pressures and temperatures.

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SKiES: The program Implementation of Allen's method for solving kinetic equation for solids from first principles

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The study of transport properties in metals is essential for both the physics of extreme states of matter and fundamental problems in solid-state physics. The most popular theoretical techniques for analyzing the transport characteristics of conductors are those that rely on the solution of the Boltzmann kinetic equation. Allen proposed a strategy [1] for solving the kinetic equation, based on a generalization of the lowest-order variational approximation approach. We introduce our software code, SKiES (Solver of Kinetic Equation for Solids), an implementation of Allen's method. The application facilitates electronic transport calculations from first principles and provides temperature-dependent solid-state transport properties over a broad temperature range. For precise Brillouin zone sampling, the Wannier interpolation approach [2, 3] is employed. The basic functions of the code and the computational workflow are described. Examples of the results for electrical resistivity and thermal conductivity calculations are provided for a range of metals. Convergence issues in the final results are highlighted, particularly those related to the Wannier interpolation procedure.
This work has been supported by the Russian Science Foundation (grant No.20-79-10398).

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Investigation of the compressibility of iron oxide in the terapascal pressure range

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In order to improve the accuracy of modeling various processes occurring with the release of energy in macroscopic volumes in soils and rocks associated with human activity, as well as natural origin, a universal wide-range multicomponent equation of state (EOS) is being developed at FSUE "RFNC-VNIIEF" using the mixture approximation. EOS of its components have been developed and experimental data on the compressibility of each of the components are required for their validation. Using the method for studying the quasi-isentropic compressibility of substances, an experiment was conducted with an explosive spherical loading device, the purpose of which was to obtain data on the compressibility of one of the main components of terrestrial soils and rocks - iron oxide Fe2O3 - in the range of terapascal pressures. A core of porous Fe2O3 (3,18 g/cm3) was located in the center of the device. Using the multi-frame X-ray complex of the Federal State Unitary Enterprise "RFNC-VNIIEF", seven X-ray images of the compression process were obtained. The experimentally recorded maximum average density of iron oxide was 17,1 g/cm3, at a calculated pressure of P = 3,7 TPa. The experiment also obtained direct data on the shock-wave compression of the material under study in the form of the position of the front of the converging shock wave recorded on X-ray photographs.

Thermodynamic function calculation for ideal gases using the “GasThermo” web application

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Inductively coupled plasma mass spectrometry (ICP-MS) is a highly sensitive analytical technique that plays a pivotal role in detecting and quantifying trace elements and isotopes in complex samples. Its precision and versatility make it indispensable across various fields, including environmental monitoring, clinical diagnostics, and materials science.

A critical challenge in ICP-MS analysis is the interference caused by background ions, which can hinder the accurate detection of target analytes and reduce the overall sensitivity of the method. Addressing this issue is essential for ensuring reliable results, particularly when analyzing samples with complex matrices.

This work introduces a set of web applications, collectively referred to as “GasThermo”, designed to calculate the thermodynamic functions of diatomic gases using quantum chemical methods. These applications provide valuable insights into the molecular interactions of atoms, aiding in the evaluation of plasma environments.

As part of this study, argon nitrides (species commonly formed in inductively coupled plasma during the analysis of organic substances) were investigated. “GasThermo” contributes to a broader suite of tools aimed at assessing the impact of background ions on ICP-MS performance, offering researchers enhanced capabilities for tackling this significant analytical challenge.

This research was supported by the Russian Science Foundation, grant No. 24-79-00112.

Investigation of the high-temperature properties of lead in liquid and near-critical states by quantum molecular dynamics

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Lead's unique physical and chemical properties make it indispensable in various industrial applications, particularly in the nuclear power industry, where it is valued for its effectiveness as a coolant and radiation shield in modern reactors due to its high density, excellent corrosion resistance and ability to absorb radiation. And accurate measurement of the critical point parameters and transport properties of lead is of paramount importance to ensure safe and efficient design and operation of nuclear reactors.

The quantum molecular dynamics method is increasingly being used to determine the physical properties of materials in temperature ranges where it is difficult to reproduce experimental data or where experiments are completely impractical. This approach is based on density functional theory and does not depend on any additional empirical data.

The aim of this work is to investigate the thermodynamic and transport properties of lead in the vicinity of the liquid-gas two-phase boundary using the QMD method. QMD calculations of a detailed grid of isotherms and isochores for the liquid phase of lead, estimation of critical parameters, thermal expansion curve, viscosity and thermal conductivityare carried out. The available relevant experimental data is also analysed and discussed.

The research was supported by the Russian Science Foundation grant No. 24-79-00136.

Equations of state of liquid phases of sodium and potassium at high pressures and temperatures

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Sodium, potassium and their mixtures are of interest because they can be used as liquid metal coolants for nuclear power plants. In this regard, it is necessary to know their properties in the entire region of liquid states, including near the evaporation region. This work discusses the thermodynamic properties of liquid phases of sodium and potassium at high pressures and temperatures. Simple equations of state with a small number of parameters are constructed for these metals near the region of the liquid–vapor phase transition. Based on the obtained equations of state, the boundaries of the evaporation region of pure metals and their mixtures are calculated. The dependence of the speed of sound on temperature at atmospheric pressure and the thermodynamic parameters characterizing the shock compression of the liquid phases of sodium and potassium are also considered. Based on a comparison of the calculation results with experimental data, the applicability regions of the developed equations of state are established. The results obtained can be used for numerical modeling of physical processes at high pressures and temperatures.

Recent advances in ab initio calculations of the thermophysical properties of metals near the liquid-gas coexistence curve

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We present our latest advancements in describing the thermodynamic, transport, and optical properties of metals from the vicinity of melting up to the critical point using the quantum molecular dynamics method. Our analysis focuses on some key metals of nuclear energy such as nickel, zirconium, and hafnium, examining their thermal expansion, enthalpy, resistivity, and normal spectral emissivity. We will demonstrate the calculated dependencies of density, enthalpy, isobaric and isochoric heat capacities, the Grüneisen parameter, and the speed of sound on temperature along the critical isobar for these metals. Additionally, we provide estimates of their critical parameters based on quantum molecular dynamics calculations of supercritical isotherms. The results of first-principles resistivity calculations for Zr, Hf, and Ni over a wide temperature range will also be discussed.
Furthermore, *ab initio* calculations of normal spectral emissivity for these metals in the liquid phase along the critical isobar will be presented.
This work has been supported by the Russian Science Foundation (grant No. 20-79-10398).

P-V-T Equation of state of a- and b-rhombohedral boron

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In our paper [1], we propose P-V-T equations of state (EoS) for a-rhombohedral boron (a-B12) and b-rhombohedral boron (b-B106) up to 100 GPa for the temperature ranges of 298-1280 K and 300-2500 K, respectively, based on the EoS obtained from the Anderson-Grüneisen model. To determine the P-V-T parameters, experimental and calculated data taken from the literature were used. The derived EoS for a-B12 and b-B106 are consistent with the data obtained using density functional theory molecular dynamics calculations in Ref. [2] with an accuracy of more than 98
The derived P-V-T EoS allow one to analytically determine the values of molar volume and density in the range of 0-100 GPa, which are necessary for thermodynamic calculations of reactions occurring under HPHT conditions, such as synthesis of diamonds at high pressure (7 GPa) and temperature (1500 oC) from C-O-H fluids without metal catalysts [3].
The work was supported by Ioffe Institute, FFUG-2024-0019.

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Measurement of metals density in solid and liquid states during microsecond pulse heating

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Fast electrical pulse heating is a prominent technique for investigation of refractory metals at high temperatures. Meanwhile, some properties of such materials are still insufficiently investigated at this temperature region. For vanadium such properties as density change during melting is of special interest. In the present paper, we describe a technique for investigation of the thermal expansion of refractory materials at high temperatures and in the melting region by pulse electrical heating [1]. The experimental method consists in fast heating of the wire sample up to the melting temperature and above in a time of about 50–150 μs due to homogeneous volumetric heat release when the electric current pulse passes through it. Heating is carried out under isobaric conditions at a static pressure of buffer inert gas (Ar) of about 5 MPa. The input energy or enthalpy change can be determined by measuring the current and the voltage drop between the potential probes in the central part of the sample. Temperature measurements are performed by a two-channel optical pyrometer that implements the spectral ratio method. Thus, by measuring the surface temperature of the sample during the experiment, current and voltage, one can determine the dependence of the enthalpy change, as well as the heat capacity. The obtained thermal expansion coefficients of vanadium in solid and liquid states can be useful both for theoretical studies in constructing wide-range equation of state for refractory metals and for solving the problems of high-temperature engineering.

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Quantum-chemical computation and thermodynamic functions of argon fluorides in the gas phase

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Argon fluorides are among the argon-containing ions observed in inductively coupled plasma mass spectrometry (ICP-MS) with argon plasma sources. To estimate the errors introduced by these ions into mass spectrometric measurements, it is necessary to know their thermodynamic properties. In previous studies, thermodynamic functions were calculated for several argides [1–4].

This work presents the potential energy curves of interatomic interactions for ArF and ArF^+ molecules, computed using various basis sets. The computations were performed with the ORCA software package [5] using the multireference configuration interaction (MRCI) method. Based on these results, the corresponding thermodynamic functions were calculated using the developed web application "GasThermo".

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Hydrogen influence on plastic relaxation at grain boundaries in aluminum

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The paper presents a molecular dynamics (MD) study of the effect of H atoms on the mechanisms of plastic deformation of Al systems during shear deformation with different structures and specific energies of grain boundaries (GB). MD calculations are performed using the LAMMPS package [1]. To describe interatomic interactions for the Al-Cu system the potential [2] is used, for the Al-H system from [3], the interaction of Cu-H was described using the Lennard Jones potential. The study carried out for the systems containing H atoms on the GB in the concentration of 1-10 at.% showed that the presence of H atoms on the GB for most of the systems did not change the mechanism of plastic relaxation. For almost all the systems considered, H strengthening was observed due to the fixation of the boundary by H atoms and an increase in stresses in the system. For a system with a misorientation angle of 36.87 *extdegree* and a specific GB energy of 694 mJ/m^2, with the addition of H atoms, an increase in stress to 715 MPa is observed; for this system without H, the maximum stress is 525 MPa. Softening with the addition of H atoms was observed for the 36.87 *extdegree* system and the specific energy of the GB of 467 mJ/m^2, the shear stresses decreased from 1020 MPa for the system without H to 894 MPa for the system with 10% concentration of H atoms near GB.

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A comparative study of some scaling and traditional models describing the densities of the liquid and the gas on the SF_6 saturation line

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In this report we consider a number of objects; among them there are: (a) the liquid (ρ_l) and the gas (ρ_g) densities on the saturation line of SF_6, (b) the average diameter (f_d), the order parameter (f_s), (c) $\Delta\rho_l = (\rho_l - \rho_c)/\rho_c$, $\Delta\rho_g = (\rho_g - \rho_c)/\rho_c$, (d) thermodynamic complexes $Z_l = \Delta\rho_l/f_s$, $Z_g = |\Delta\rho_g|/f_s$. One of the purposes of our study is to get numerical data on complexes (Z_l, Z_g, $ur = f_d/f_s$, etc.) in the range ($2\times10^{-8} < \tau < 0.3$). In accordance with the goals, the authors consider tasks I…III. Due to tasks I, we are generating the initial array (SA) on the bases of experimental (ρ_l, ρ_g, T) data in the range ($2\times10^{-8} < \tau < 0.3$) (step 1). In the second step, we are building model A ($f_s = B_{s0}\tau^{\beta} + B_{s1}\tau^{\beta+\Delta} + \ldots$) and model B ($f_d = B_{d0}\tau^{2\beta} + B_{d1}\tau^{1-\alpha} + \ldots$), which work in the range ($2\times10^{-8} < \tau < 0.3$) satisfactorily and follow to the scaling theory of critical phenomena (ST). In the frame of tasks II, we are investigating the equations C ($Z_l = 1 + ur = 1 + ur_{bas} + (B_{d1}/B_{s0})\tau^{1-\alpha-\beta} + \ldots$, $Z_g = 1 - ur = 1 - ur_{bas} - (B_{d1}/B_{s0})\tau^{1-\alpha-\beta} + \ldots$), here $ur_{bas} = (B_{d0}/B_{s0})\tau^{\beta}$. Using the SA array and C models, we calculate (Z_l, Z_g, ur_{bas}) data, experimental ($Z_{l\ exp}$, $Z_{g\ exp}$, ur_{bas}) data and construct a liquid as well as gasose branches of the binodal in these coordinates. In accordance with tasks III empirical equations ($Z_{l\ eff}(x_1, x_2, \tau)$, $Z_{g\ eff}(x_1, x_2, \tau)$) is being developed (step 1). In the second step, we determine (Z_l, Z_g, ur_{bas}) data, which are connected with some literature (ρ_l, ρ_g, T) values.

Study into the efficiency of stochastic optimization methods by the expamle of a multiphase equation of state for aluminum

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The paper is devoted to the study of two stochastic methods of multivariable function optimization, specifically, the real genetic algorithm and the particle swarm method. Parametric analysis was performed and recommendations were formulated concerning the choice of internal parameters for these methods. The root-mean-square deviation of calculated and "experimental" thermodynamic quantities was taken as the objective function of optimization. Here "experimental" values are actually results of a calculation with the known parameters of a multiphase equation of state of aluminum. It is shown in what these methods are advantageous and disadvantageous when applied to EOS parametrization.

Organization of neural network for predicting the potentials of interatomic interaction

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The report presents a program that implements an object- oriented model of an artificial neural network for predicting the potentials of interatomic interaction. The complete functional form of a neural NNP network, supported activation functions, radial and angular symmetry functions (ACSF), and the atomic environment detection function are considered. (circumcision). The description of the user interface, online and batch modes of operation, validation and approbation of the neural network is presented. A converter of atomic systems data from the Fortnet open software package has been developed. Examples of data obtained in the process of batch training of a neural network are shown. To parallelize the learning process, an updated NNP network architecture consisting of atomic subnets is proposed.

Plastic deformation in nanocrystalline aluminum at twist grain boundaries

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MD study of mechanical response and elastic-plastic behavior of Al with different grain boundaries (GB), misorientation angles, specific energies, and Cu atom concentrations is performed. Systems containing symmetrical twist GBs with misorientation angles of 4 *extdegree*, 12.68 *extdegree*, 36.87 *extdegree* and 43.61 *extdegree* with a misorientation axis [100] were considered. For each angle, several GBs were created, differing in structure and specific energy. For angles of 4 *extdegree* and 18.435 *extdegree*, systems containing Cu atoms segregated at GB in different concentrations were considered. Depending on angle, specific energy and the Cu atom concentration various critical shear stresses and relaxation mechanisms (grain rotation and dislocation processes) were observed. Rotation occurs in all systems when the shear stress exceeds a threshold value specific to a given boundary and is accompanied by an increase in Sxx and Szz stresses in the system, which leads to the shear stress increase due to change in the elastic constants of the lattice. Dislocation nucleates at a relatively low shear stresses in the systems. For 4.00 *extdegree* and 12.68 *extdegree* angles, there is average shear stresses increase after dislocation formation without their motion. The reason for dislocation loop formation in this case is the local stresses formed at the GB due to the contact of grain parts. The nucleated dislocations can be absorbed by the opposite GB, after that there are no mobile dislocations in the system and grain rotation continues. The average shear stresses after the recession associated with dislocation processes continue to grow with characteristic dependence.

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Method for calculating the critical amplitude of the coexistence curve

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Based on experimental information on the density of saturated vapor and saturated liquid in the vicinity of the critical point, the critical amplitude B_0 was calculated for different values of the critical index β of the coexistence curve and the correlation dependence $B_0 = B_0(\beta, \omega)$ was determined, where ω is the acentric factor of the substance. The correlation $B_0 = B_0(\beta, \omega)$ was tested on the basis of 24 substances for which the literature provides data on $B_0 = B_{0,exp}$ at $0.315 \le \beta \le 0.385$ and $0 \le \omega \le 3.65$. The deviations of the $B_{0,exp}$ values from those calculated by the correlation $B_0(\beta, \omega) = c_1 + c_2\omega + c_3\beta + c_4\omega^3$ for all the substances considered do not exceed 7% in absolute value ($c_1 = -2.47368$, $c_2 = 1.36533$, $c_3 = 12.06886$, $c_4 = -1.23152$). The hypothesis that the amplitude B_0 depends only on the critical index β, $B_0 = B_0(\beta)$, is discussed. It is established that the dependence $B_0 = B_0(\beta)$ proposed in [?] leads to significant, up to 37%, deviations of the calculated values of B_0 from the values of $B_{0,exp}$. It is shown that the correlations and $B_0 = B_0(\omega)$ [?] agree with each other at values $0.323 < \beta < 0.328$, however, in the case of $B_0 = B_0(\omega)$ [?], the discrepancies in the values of $B_0 = B_0(\omega)$ and $B_{0,exp}$ for all 24 substances exceed 10%. The position that the critical amplitude of the coexistence curve is an individual characteristic of a substance, which depends on the degree of non-sphericity of the substance molecules and the compressibility factor, Z_c, is discussed.

Method for calculating the equilibrium properties of individual substances within the framework of scale theory

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The phenomenological theory of the critical point [1] is used, based on the method of pseudo-critical points and Benedek's hypothesis [2]. The proposed method for calculating the equilibrium properties of individual substances is based on the expression for entropy:

$$\Delta S \cdot X_i^{(1-\alpha)/\phi_i} = \varphi_0 + \varphi_2 \cdot m^2, m = \Delta\rho \cdot X_i^{\beta/\phi_i}. \tag{1}$$

Here $\Delta S = (\rho T_c/p_c)[S(\rho,T) - S_0(\rho,T)]$; p_c is the critical pressure; T_c is the critical temperature; $S_0(\rho,T)$ is the regular function; $\Delta\rho = \rho/\rho_c - 1$; ρ_c is the critical density; φ_0 and φ_2 are constants; the function X_i successively takes on the values of isochoric heat capacity ($X_1 = C_v$, $\phi_1 = \alpha$), isothermal compressibility coefficient ($X_2 = K_T$, $\phi_2 = \gamma$) and isobaric heat capacity ($X_3 = C_p$, $\phi_3 = \gamma$);α, β and γ are critical indices.

Using known thermodynamic equalities based on (refm1), a unified fundamental equation of state (UEoS) in the form of Helmholtz free energy has been developed. The proposed UEoS in the asymptotic vicinity of the critical point satisfies all the requirements of the large-scale theory.

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Atomistic modeling of 5CB phase transition and diffusion

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The diffusion of molecular motors in liquid crystals in the experiment [1] is used as a parameter in a continuous model, that can be refined with MD methods. For that reason, the model of LC reproducing general properties should be developed. The phase transition from isotropic to nematic phase at temperature T = 300 K is observed in a long 1.8 μs MD simulation in the GAFF force field [2]. The order parameter gradually grows from 0.11 to 0.57 via simulation for 1 μs and remains stable afterwards. Order parameter and density values correspond to the experimental values [3, 4]. With anisotropic radial distribution function it is checked that observed nematic phase is indeed nematic, not smectic, for instance. By the annealing procedure (from T = 300 K to T = 380 K) it is checked that the temperature order parameter dependence is not influenced by the annealing speed. Thermodynamic stability at several temperatures is checked for two different initial phases, nematic and isotropic. Temperature dependence of diffusion coefficients is calculated and comparison with other experimental and computational works is done [5, 6].

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The influence of intercalation on the surface energy of graphene-like materials.

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Using the electron density functional theory, the surface energy of pure and intercalated graphene-like materials [1] is calculated. It is shown that after intercalation by donor-type alkali metal atoms, the surface energy value of graphene-like materials increases. In the case of intercalation by acceptor-type atoms, the surface energy decreases. All calculations were performed using the Quantum Espresso program [2].
The research was funded by the Russian Science Foundation (project No. 24-22-20102)

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The emission of neutrons in collapsing bubble filled by hydrogen isotopes

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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 $d + d -> {}^3He + n$ reaction, as well as the residual activity of tritium synthesized in the $d + d -> t + p$ channel. Tritium will decay according to the ${}^3H -> {}^3He + e + \tilde{\nu}$ 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 signals 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], as well as the analytical model developed in work [3].

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Study of the isentropic compressibility of solid phase carbon dioxide in the region of ultra-high pressures

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The paper presents the design and results of experiments on isentropic compression of solid carbon dioxide to pressures above 5Mbar in a device based on a magnetocumulative generator. The initial state of the compressed samples corresponded to atmospheric pressure and a temperature close to 150K. The occurrence of electrical conductivity was recorded in the studied samples, and the density and pressure were also determined at different moments of the compression process.
The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 "Research in high and ultrahigh magnetic fields"

Enhancement of spin-orbit coupling in doped graphene

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Using first-principles calculations, the possibility of enhancing the SOC in graphene due to its doping by cadmium and tellurium atoms has been shown. For the CdC_{15} structure, the spin splitting value was $E_{SOC} = 0.23\ eV$. Co-doping of graphene by cadmium and tellurium leads to a lower spin-orbit splitting value $E_{SOC} = 0.08\ eV$. At a low concentration of doped atoms, as in the case of the CdC_{31} structure, splitting of graphene energy levels is not observed. In conclusion, we note that the enhancement of SOC in graphene and a sufficiently large band gap induced by doped atoms is an important factor for the creation of a 2D topological insulator based on graphene operating at room temperatures [1].

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Electrostatic energy of solid binary ionic mixtures

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We study the electrostatic energy of binary ionic mixtures in the form of ordered Coulomb crystals. We consider different binary bcc and fcc like lattices, accurately calculate their electrostatic energies and approximate them by a unified equation. A detailed comparison with previous results is made, particularly, using in the linear mixing rule approximation. The obtained approximation expression is used to analyze the phase diagrams of degenerate matter in the interiors of degenerate stars.
This work was supported by the Russian Science Foundation (grant number 24-12-00320).

Modeling of ion transport in ether-based liquid membranes

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To accelerate the development of liquid ion-selective barriers based on ethers, we compare the all-atom force fields GAFF, OPLS-AA with charge correction 1.14*CM1A (OPLS-AA/CM1A), CHARMM version 36 (CHARMM36), and COMPASS for diisopropyl ether (DIPE) to determine the most appropriate model for further molecular dynamics simulations of liquid membranes. Utilizing the selected force fields, we calculate the density and shear viscosity of DIPE across a temperature range of 243–333 K. Furthermore, we use CHARMM36 with mTIP3P water model and COMPASS with its own water model to evaluate the mutual solubility and interfacial tension between DIPE and water, estimate the partition coefficients of ethanol in DIPE + Ethanol + Water systems. Based on our comparative study, we conclude that CHARMM36 is the most suitable force field for modeling ether-based liquid membranes. These results were published in [1]. Subsequently, the CHARMM36 force field was used to model solutions of lithium and chloride ions in water and DIPE. Transport properties of ions, such as mobility and diffusion coefficients, and structural properties, including pair correlation functions, were investigated. The diffusion coefficients and ion mobility were estimated based on the steady-state ion current under an applied constant external electric field. The study was conducted for solutions with ion concentrations of 0.01 and 0.1 M and at various strengths of the external field.

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Anomalous spatial charge profiles of plasma as manifestation of phase transitions in modified one component plasma model

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The paper discusses the possibility of the appearance of discontinuities in the results of calculations of equilibrium space charge profiles in the vicinity of the source of inhomogeneity [1]. specific manifestation of the above-mentioned nonideality effects in the studied equilibrium charge profiles in the form of an ultradisperse two-phase mixture ("mixed phase"). The proposed general conclusion is the statement that the concept of mixed phase is not an attribute of exclusively astrophysical applications, but is a fairly general property of computational schemes used to describe equilibrium inhomogeneous Coulomb systems [3].

[1] Iosilevski I, Chigvintsev A, Noginova L and Zorina I 2022 *High Temperature* **60** 325

[2] Iosilevski I, Chigvintsev A, Noginova L and Zorina I 2018 *J. of Phys. Conf. Ser.* **946** 012092

Exotics mixed phase appearance in calculation of spatial charge profiles of plasma

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The paper discusses the possibility of the appearance of discontinuities in the results of calculations of equilibrium space charge profiles in the vicinity of the source of inhomogeneity [1]. These discontinuities are considered as a kind of micro-level manifestation of phase transitions in the local equation of state (EOS), which is used to describe the non-ideal electronic and/or ionic subsystem within the framework of the quasi-homogeneity approximation ("local density") [2].Particular attention in this work is paid to the possibility of a specific manifestation of the above-mentioned nonideality effects in the studied equilibrium charge profiles in the form of an ultradisperse two-phase mixture ("mixed phase"). The proposed general conclusion is the statement that the concept of mixed phase is not an attribute of exclusively astrophysical applications, but is a fairly general property of computational schemes used to describe equilibrium inhomogeneous Coulomb systems [3].

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New web application for approximation of thermodynamic functions of diatomic gases

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Temperature-dependent thermodynamic functions are essential for thermodynamic modeling, providing the foundation for realistic descriptions of physicochemical processes. Such data must be structured to represent the behavior of reactants across any temperature range. Traditionally, the Glushko handbook and IVTANTHERMO-online information system [1] utilizes polynomial representations for thermodynamic functions:

$$\Phi^\circ(T) = \phi_1 + \phi_2 \ln X + \phi_3 X^{-2} + \phi_4 X^{-1} + \phi_5 X + \phi_6 X^2 + \phi_7 X^3,$$

$$C_p^\circ(T) = \phi_2 + 2\phi_3/X^2 + 2\phi_5 X + 6\phi_6 X^2 + 12\phi_7 X^3$$

This study introduces a modern web application designed to approximate fundamental thermodynamic functions using specified polynomial forms. The approximation algorithm is based on dividing the entire temperature range into a variable number of intervals, as described in [2]. This approach ensures higher accuracy and adaptability for a wide range of temperature-dependent datasets.
The developed application also features a dedicated API (Application Programming Interface), enabling users to remotely approximate dependencies of thermodynamic functions for ideal gases.
This research was supported by the Russian Science Foundation (RSF), grant No.24-79-00112.

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Calculation of viscosity using quantum molecular dynamics simulation and transverse current correlation function

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This study investigates the viscosity of liquids using data obtained from molecular dynamics simulations. The viscosity was calculated via a method based on the transverse current correlation function [1–3], which captures the system's microscopic dynamics. Special attention was given to the convergence of results concerning the number of particles in the simulated system. We introduce a novel technique for integrating the correlation function, offering a robust method for analyzing transport properties. Classical molecular dynamics simulations were performed for liquid aluminum, while quantum molecular dynamics simulations were used for liquid lead to determine the viscosity as a function of temperature under isobaric conditions.

We compared our results with experimental data and validated our findings through extensive verification. The results highlight the impact of system size on the accuracy of viscosity measurements and confirm the efficacy of this approach for studying the transport properties of liquids and, in particular, liquid metals.

The work is supported by the Russian Science Foundation (project No. 24-79-00136).

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First-principles calculation of resistivity and normal spectral emissivity for hafnium

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Hafnium is a chemically inert, refractory metal widely used in the nuclear industry. The resistivity and optical properties of hafnium at temperatures up to 10 kK have been studied using first-principles methods through quantum molecular dynamics simulations.
The Kubo–Greenwood formula was applied to determine the dynamic electrical conductivity. Based on the computed conductivity, the optical properties–such as normal spectral emissivity, reflectivity, and refractive index–were derived using the Kramers–Kronig transformation.
The influence of various exchange-correlation functionals on the calculated properties of Hf was analyzed.
This work has been supported by the Russian Science Foundation (grant No. 20-79-10398).

Fatigue damage staging and crack advance monitoring in space constructions under combined loading

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The fatigue damage staging and crack advance monitoring for space construction are studied for combined quasi-static, dynamic and very-high cycle loads analyzing the damage induced roughness in the process zone (PZ) and fracture surface pattern depending on the load history. Very high fatigue load that is typical for space constructions is characterized by the extended range of damage staging revealing characteristic pattern on the fracture surface related to small crack initiation, transient regime of small crack growth up to the so-called Paris crack length and the propagation of this crack in damaged material. The roughness pattern gives important data concerning accommodation of material to the defect kinetics. Non-destructive testing is proposed based on the roughness analysis to estimate scaling invariants (the Hurst exponent) as the structure sensitive parameter in kinetic equation for damage (defect density) parameter and power exponent in the generalized Paris law. The monitoring of space construction will be realized by the replica technique for surface crack and fracture surface analysis using the laser microscopy by MIM-320 original set-up. To decrease the level of coherent microscopy noise the original technique of difference frames was proposed.

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 April 23, 2024).

Experimental study of thermal expansion of high refractory carbides near its melting point at high temperatures

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The experimental study of the thermal expansion of refractory titanium and molybdenum carbides, in particular the effect of stoichiometry on the thermal expansion coefficient under fast electric heating 10^7 to 10^8 K/s are of great interest nowadays. The novelty of the proposed approach is the use of precision technology of optical pyrometry, high-speed digital visualization of the thermal expansion of the materials under study, as well as the possibility of using various heating rates. The chosen approach allows us to investigate the thermal expansion coefficient of refractory carbides over a wide range of high temperatures for stoichiometries previously unstudied. Direct measurement of the sample temperature makes it possible to switch off the heating at a given temperature in real time (during the experiment). The thermal expansion coefficients of refractory carbide TiC of stoichiometric composition were experimentally determined at high temperatures (up to 3.2 kK) and buffer gas pressure up to 0.1 GPa. In pulse experiments, a melting plateau and an extended region of a two-phase zone were recorded on thermograms, which make it possible to study the melting process in similar metal–carbon systems of various compositions. An improved method for measuring thermal expansion by sample glow, which has a high response speed of up to 4 μs, was used in the experiments. The obtained data on the thermal expansion of TiC show good agreement with available literature data in the range up to 2.8 kK.

X-ray measurements in experiments on constructing equations of state of substances

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Pulse radiography was widely used in the development of the megagauss-range explosive magnetic field generator (MC-1). It is also successfully used to construct equations of state of substances in the megabar pressure range using devices based on MC-1. The essence of the radiographic method lies in measuring the density of the test and reference substances. For this purpose, during the experiment, radiography of the compression chamber is performed at one of the moments in time when the substances are compressed to megabar pressure. The compression of the test and reference substances is determined from the images of the chamber and samples inside it obtained on x-ray photographs. Now, knowing the initial densities of the test and reference substances, their densities in the compressed state are calculated. And based on the density of the reference using its known isentrope, the pressure in it is determined and thereby (after taking into account small gradient corrections) in the test substance.

The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 “Research in high and ultrahigh magnetic fields”.

The Kob–Andersen model crystal structure: Genetic algorithms vs spontaneous crystallization

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The crystal structure of the Kob–Andersen mixture has been probed by genetic algorithm calculations. The stable structures of the system with different molar fractions of the components have been identified, and their stability at finite temperatures has been verified. It has been found that the structures of composition AB_n, where n = 2, 3, or 4, can be formed in the system. Metastable structures with compositions $AB_{0.4}$ and $AB_{0.58}$ have also been identified. Molecular dynamics simulations of spontaneous crystallization from liquid have been performed. We find several stable crystal phases which correspond to the concentrations of the components $c_{\mathrm{B}} = 0, 1/2, 2/3, 3/4$ and 1. At the same time these structures are not observed upon spontaneous crystallization of a liquid with given concentration. For this reason these structures are difficult to obtain in a simple molecular dynamics simulation, which prevented their discovery before. At the same time there are some indirect evidences of existence of the different crystal structures at $c_{\mathrm{B}} > 0.5$, for instance, the kinks on the isothermal dependence of viscosity on the concentration of the components [1].

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4. Methods of Mathematical Modeling

Numerical Investigation of Temperature Effects on Nucleation Rate

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This work employs molecular dynamics simulations to investigate both isothermal and non-isothermal vapor–liquid nucleation kinetics in a system of particles interacting via the Lennard-Jones potential. For the first time, the temperature size distribution has been determined. Starting at the monomer temperature as a reference, it goes down slightly, but as the cluster size approaches the critical one, the temperature reaches its value of monomers, then starts to gain faster. The temperature distribution over cluster sizes defines the distribution of their number densities and thereby controls the vapor nonideality, which in turn can strongly affect the nucleation rate. It has been shown in [1] that taking into account vapor nonideality results in a significant difference in the nucleation rates. Thus, knowledge of cluster temperature is crucial for analytical models to accurately determine vapor supersaturation and the actual non-isothermal nucleation rate. A special simulation method was used, in which all clusters that had grown to a sufficiently large size were removed from the system, and the particles that formed them were returned to the system in the form of monomers. Nucleation rates and critical cluster sizes for both isothermal and nonisothermal cases have been determined over a broad range of supersaturations. The results obtained for nonisothermal nucleation rates show satisfactory agreement with the theoretical model [2], which preditcts a decrease in the nucleation rate for nonisothermal case.

[1] Perevoshchikov E E and Zhukhovitskii D I 2024 *JETP* **165**(1) 73–88
[2] Zhukhovitskii D I 2024 *J. Chem. Phys.* **160**(19) 194505–1–194505–20

Solving high-linear dynamic problems using fixed meshes in LOGOS software package

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The paper describes the functionality of the LOGOS-Mechanical [1] software module,which is part of the multifunctional domestic LOGOS [2] software package, in terms of solving high-nonlinear dynamic strength problems using fixed unstructured meshes.

In the LOGOS-Mechanical software module, when computing gas-dynamic and elastoplastic currents, splitting into Lagrangian and Euler stages is used. At the Lagrangian stage, mesh nodes move with matter and with intense currents, the quality of the mesh can noticeably deteriorate. To maintain acceptable mesh properties, a Euler stage is completed, which consists of a procedure for adjusting the mesh and recalculating the values from the Lagrangian mesh to the corrected one. If the mesh returns to its initial position during the correction step, the mesh is stationary.

The paper describes the functionality of the LOGOS software package in terms of solving high-nonlinear dynamic strength problems using fixed unstructured meshes, methods for constructing a fixed unstructured mesh, features of methods and algorithms of numerical simulation at the Lagrangian and Eulerian stages, as well as principles of parallelization.

Finally, we provide the results of several computations using fixed meshes in LOGOS-Mechanical computational module.

[1] Dyanov D 2018 *VANT. Ser.: Mat. Mod. Phys. Proc.* 3–14

[2] LOGOS software package `http://logos.vniief.ru/products/logos`

Formation of a cylindrical cavity in LiF crystal by X-ray pulse

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Volumetric modification of materials requires lasers with X-ray emission. It was demonstrated [1] that a free-electron laser with a single X-ray pulse of 9 keV photons can form a long cylindrical cavity in LiF crystal. The plasma channel created by such a pulse generates a divergent cylindrical shock wave (SW) with a pressure of $\sim$ 1TPa, which can lead to damage, melting, and polymorphic transformations in materials under study.
We analyzed the formation and propagation of pressure waves in LiF using continuum smoothed particle method (SPH) and molecular dynamics (MD) simulations. A sequence of processes leading to formation of a long cavity with a flat bottom has been identified. At high energy density near the sample surface, SPH and MD simulations both show the formation of an initial channel of low-density hot fluid due to radial material movement in a divergent plastic SW. After reaching the maximum size, the radius of the channel remains practically unchanged. At lower density of energy deposited in the depth of material, the channel is filled with dense melt, in which tensile stresses arise by heat conduction to surrounding cold material. MD simulation shows that a flat bottom of cylindrical cavity is formed due to the stop of propagation of cavitation bubble nucleation front when it meets a crystallization front in the melt [2].

[1] Makarov S, Grigoryev S, Inogamov N and et al 2023 *Opt. Express* **31** 26383

[2] Makarov S, Grigoryev S, Zhakhovsky V and et al 2024 Formation of high-aspect-ratio nanocavity in LiF crystal using a femtosecond of X-ray FEL pulse (*Preprint* `arXiv:2409.03625`)

Description of the onset and damping of transverse collective excitations in Yukawa plasmas within the self-consistent relaxation theory

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This work is devoted to the development of a theoretical description of transverse collective excitations in liquid state strongly coupled Yukawa plasmas. Liquids are known to be characterized by a constant volume without shape conservation, they can flow. The latter implies that the liquid should lack shear stiffness. However, as a number of experiments show, the presence of shear stiffness is characteristic of liquids on small spatial and temporal scales. This is due, first of all, to the presence of near-order in the arrangement of liquid particles, which leads to the manifestation of quasi-solidification properties. Obviously, these properties will be most pronounced for liquids in states close to the phase transition to the solid state. The paper will present a theoretical formalism that allows us to describe the conditions for the origin and existence of transverse collective excitations in a model Yukawa liquid. The approach is based on the self-consistent relaxation theory of collective dynamics of multiparticle systems. In the framework of the proposed formalism, analytical expressions describing the spectra of transverse collective excitations and the corresponding dispersion characteristics are obtained for the first time for the intermediate screening regimes and near the melting curve. The conditions of onset and damping of quasi-solid-state collective excitations are described.
This work is supported by the Kazan Federal University Strategic Academic Leadership Program (PRIORITY- 2030).

Decoding crystal structures: a deep learning approach to the phase problem

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Our research builds upon and extends the work presented in [1], offering a novel neural network approach to solve the crystallographic phase problem with a resolution of just 2 Å. By synthesizing millions of artificial structures along with their corresponding diffraction data, we have used an extensive training dataset for the neural network. This pioneering approach enables ab initio phasing with only 10%to 20% of the data conventionally needed, thereby challenging the prevailing belief that atomic resolution is essential for structural solutions. The neural network adeptly handles data within standard centrosymmetric space groups and moderate unit cell dimensions, highlighting its potential to broaden the applicability of neural networks for the phase problem. This method holds significant promise for enhancing the structural determination of weakly-scattering crystals, such as metal-organic frameworks and nanometer-scale materials.

[1] Larsen A S, Rekis T and Madsen A Ø 2024 *Science* **385** 522–528

Considering the photofission reaction in modeling of the chain reaction of ^{235}U fission in the uranium cube by the TPT3 program

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The TPT3 program is developed in Dukhov Automatic Research Institute for the high-performance parallel simulation of the particle transport on the multicore CPU and GPGPU architectures with the SIMD instructions. One of the key features of the TPT program is the voxel geometry, which simplifies the massively parallel computations. The TPT3 program can propagate neutrons, gammas and atomic ions in matter. All propagated particles can have big weights. Each fission reaction provides one secondary neutron and one secondary gamma with weights, which are equal to the projectile weight multiplied by the differential multiplicities of the fission reaction. Thus the number of the propagated particles does not increase, while the weights of the propagated particles can be very big. The weighted particles help to simulate the nuclear chain reactions with the individual concentrations of elements in each voxel. As the weights of the propagated neutrons can be extremely high, the TPT3 program can simulate the nuclear fuel burnup and the dynamic modification of the voxel element concentrations including the fission fragments. Taking into account the radiation capture reactions, the TPT program can generate heavy isotopes of uranium in the voxel media. The influence of the photofission reaction on the simulated results of the fuel burnup is diskussed.

Modeling of particle acceleration in star clusters with 3D-MHD simulations

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Young compact clusters of massive stars contain dozens of O-, B- and WR-type stars with fast powerful winds in a small $\sim$ pc radius. The acceleration of particles by ensembles of shocks and waves of compression and rarefaction in the turbulent environment of young massive star clusters (YMSCs) is an alternative to the standard paradigm of Galactic cosmic rays acceleration on supernova shocks. In recent years, the topic is of great interest due to the fact that modern gamma- and X-ray observatories are detecting the radiation from YMSCs (e.g. Westerlund 1, 2), which indicates on particle acceleration processes in these objects. We study propagation and acceleration of particles in a YMSC with the help of 3D magnetohydrodynamic (MHD) modeling using PLUTO, an open source code based on the numerical solution of MHD equations with the Godunov scheme [1]. The code allows modeling of the turbulent environment of YMSCs and obtaining crucial for particle acceleration values of velocity, density and magnetic field inside the cluster core [2]. The particle module implemented in PLUTO allows solving the equations of motion for test charged particles together with MHD equations for the medium. We obtained that protons acceleration up to hundreds of TeV takes place in the cluster core near the termination shocks of O-stars, which are surrounded by shocks of their neighbour stars. The particle spectra and spatial distribution are discussed.

[1] Mignone A, Bodo G, Massaglia S, Matsakos T, Tesileanu O, Zanni C and Ferrari A 2007 *ApJS* **170** 228–242 (*Preprint* `astro-ph/0701854`)

[2] Badmaev D V, Bykov A M and Kalyashova M E 2022 *MNRAS* **517** 2818–2830 (*Preprint* `2209.11465`)

Decoding crystal structures: a deep learning approach to the phase problem

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Our research builds upon and extends the work presented in [1], offering a novel neural network approach to solve the crystallographic phase problem with a resolution of just 2 Å. By synthesizing millions of artificial structures along with their corresponding diffraction data, we have used an extensive training dataset for the neural network. This pioneering approach enables ab initio phasing with only 10%to 20% of the data conventionally needed, thereby challenging the prevailing belief that atomic resolution is essential for structural solutions. The neural network adeptly handles data within standard centrosymmetric space groups and moderate unit cell dimensions, highlighting its potential to broaden the applicability of neural networks for the phase problem. This method holds significant promise for enhancing the structural determination of weakly-scattering crystals, such as metal-organic frameworks and nanometer-scale materials.

[1] Larsen A S, Rekis T and Madsen A Ø 2024 *Science* **385** 522–528

Coherent structures in the emulsion containing active micromotors

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The paper presents a two-phase hydrodynamic model of active motion in the emulsion containing micromotors. The liquid phase is considered as a continuum while dispersed droplets (active micromotors) are considered as separate particles exposed to the action of the active force, interacting with the liquid medium and with each other. The origins of the active forcing are not specified, so the model describes a general case that allows distinguishing of the basic patterns intrinsic to any active colloid. The interaction between phases is considered in the approximation of the Stokes law, while the interaction between active droplets is varied from elastic collisions to the alignment of droplets motion and their clustering. Numerical simulations with the use of proposed model demonstrate the generation of the coherent structures in both liquid and droplets motion. Herewith, the generated flow patterns are described well by the laws intrinsic to the developed two-dimensional turbulence. The forcing scale corresponds to the characteristic scales of active droplets interaction and the kinetic energy of active motion is distributed between the large-scale coherent structures and smaller scales where the energy is transferred to the liquid. In turn, the energy transferred from active droplets to liquid is partly dissipated due to the viscous friction and partly transferred to the larger scales generating coherent structures of liquid motion. In such a way the basic features of active colloids motion are reproduced and a new information about the flow patterns developed in active colloids is obtained. Further development of the proposed model and its parametric analysis would help to get more information useful for active colloids applications.
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The effects of ion dynamics on Stark-Zeeman spectra in plasma

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The analysis of the neutral hygrogen spectral line-shapes is often used for divertor plasma diagnostics [1]. However, it is necessary to deal with two fundamental difficulties to perform correct calculation of the spectral line profiles of hydrogen and its isotopes in tokamak divertor. Firstly, due to the simultaneous presence of the magnetic field created by the experimental set up and the electric plasma microfield, to diagonalize the atom Hamiltonian it is necessary to solve three-dimensional problem. Secondly, the plasma density in a divertor is relatively low: $N_e \approx 10^{13} - 10^{17}$ cm^{-3}. Under such conditions, it is necessary to take into account the effects of ion thermal motion on the spectral line formation in plasma. It is non-trivial problem to carry out numerical calculations taking into account both effects mentioned above. Nevertheless, in the present work the simple approach for performing such calculations is presented. The effect of ion thermal motion on Stark broadening is taken into account via Frequency Fluctuation Model (FFM) [2]. It is shown that the last modification of the FFM, performed by the authors of this work [3], leads the good agreement with molecular dynamics data.

[1] Gorbunov A, Mukhin E, Burgos J, Krivoruchko D, Vukolov K, Kurskiev G and Tolstyakov S 2022 *Plasma Physics and Controlled Fusion* **64** 115004
[2] Talin B, Calisti A, Godbert L, Stamm R, Lee R and Klein L 1995 *Physical Review A* **51** 1918–1928
[3] Letunov A, Lisitsa V, Loboda P and Novikov A 2024 *JETP Letters* **120** 115–120

Atomistic simulation of nitrogen defects in diamond with machine learning potential

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Defects of diamond crystal lattice have a significant impact on its physical properties. It is possible to use natural and synthetic diamonds in quantum technologies, employ defects as nanomarkers in industrial tracing and study laser generation of defects [1]. There is a lot of data on the dynamics of nitrogen atoms and the dynamics of vacancies separately, but their cooperative behavior and the transformation of one center into another has not been sufficiently figured out [2]. In this work dynamics of the "nitrogen-vacancy" point defects type was studied by the molecular dynamics method in the LAMMPS package [3] in the temperature range 3000- 3500 K. It is shown that the NV and NV_2 centers are localized, while the NV_3 center actively diffuses. A comparison of the evolution of NV_3 center and H3 center surrounded by 2 vacancies is proposed. Calculations of energy characteristics were carried out, a qualitative comparison with the available literature data and the results of first-principles approach was made. The work was carried out using a machine-learning potential of the MTP type [4].

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[2] Kudryashov S I, Danilov P A, Vins V G, Kuzmin E V, Muratov A V, Smirnov N A, Pomazkin D A, Paholchuk P P, Vasil'ev E A, Kirichenko A N *et al.* 2024 *Carbon* **217** 118606

[3] Plimpton S 1995 *Journal of computational physics* **117** 1–19

[4] Novikov I S, Gubaev K, Podryabinkin E V and Shapeev A V 2020 *Machine Learning: Science and Technology* **2** 025002

Numerical simulation of an experiment with planar array of aluminum wires using FLUX-3D code

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The results of numerical simulation of an indicative experiment in an experimental series with aluminum planar arrays on a pulsed power generator supplying current pulse with an amplitude of 2 MA and a rise time of 1 mks are given. Calculations of the experiment with a planar array with a width of 135 mm, consisting of 28 Al wires with a diameter of 26.8 microns and a length of 25 mm, were carried out using the three-dimensional magneto-hydrodynamic code FLUX-3D [1] in a multi-group (spectral) diffusion approximation of radiation transfer in plasma and taking into account the phenomenon of prolonged plasma ablation from the array wires. The results of numerical modeling reproduce the main characteristics of the aluminum plasma compression recorded in the experiment - implosion time, energy and time parameters of the generated X-ray pulse both in the full spectrum and in the quantum energy range above 1 keV. The efficiency of generating Ka-line of aluminum when powering planar array with a microsecond current pulse has been confirmed.
The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 ”Research in high and ultrahigh magnetic fields”

[1] Orlov A P and Repin B G 2014 *IEEE Transactions on Plasma Science* **43** 2515–2519

Coupling of smooth particle and finite volume hydrodynamics 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.

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[2] Menshov I S 2014 *Journal for Numerical Methods in Fluids* **76** 109–127
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[4] Marrone S e a 2010 *Journal of Computational Physics* **229** 3652–3663

Electronic correlations in $V_2(Te,Se)_2O$: A DFT+DMFT study

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Electron-electron interactions are widely accepted the underlying physical mechanism explaining the diversity of unusual fermionic states in quasi-two-dimensional materials. Recently, a new class of correlated van der Waals oxychalcogenides, including V_2Te_2O [1] and V_2Se_2O [2], has been synthesized. These materials exhibit unusual properties including anomalous log(1/T) temperature dependence of resistivity, correlation-induced localization effects and significant electron-mass renormalization, that cannot be explained within the picture of weakly interacting electrons implying a significant role of Coulomb correlation effects.

In this work, we explore the effect of Coulomb correlations on the electronic structure of V_2Te_2O and V_2Se_2O using a computational framework combining density functional theory (DFT) and dynamical mean-field theory (DMFT). In V_2Te_2O, Coulomb correlations induce significant quasiparticle mass renormalization for the vanadium $3d$ states, offering an improved description of the Sommerfeld coefficient [3]. For V_2Se_2O, it drives a critical redistribution of spectral weight at the Fermi level, leading to a gap opening in the electronic spectrum, consistent with experiments. These findings suggest V_2Se_2O behaves as a correlation-assisted Slater insulator and highlight the pivotal role of Coulomb correlations in shaping the electronic properties of both materials. This work was supported by the Russian Science Foundation (project no. 24-12-00024).

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[2] Lin H, Si J, Zhu X, Cai K, Li H, Kong L, Yu X and Wen H H 2018 *Physical Review B* **98** 075132

[3] Skornyakov S, Trifonov I and Anisimov V 2024 *JETP Letters* 1–6

Calculation of the ionic composition of a hot non-LTE plasma using a superconfiguration model

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Calculations of the average ion charge of hot non-LTE plasmas of germanium, aluminum and gold have been performed within the framework of the superconfiguration model [1], taking into account one-electron processes. The calculations were compared with the results of the average atom model obtained with the RESEOS code [2]. A good agreement between the data was obtained.

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[2] Ovechkin A, Loboda P, Korolev A, Kolchugin S, Vichev I Y, Solomyannaya A, Kim D and Grushin A 2022 *Matter and Radiation at Extremes* **7** 064401

Local structure, thermodynamics, and melting of boron phosphide at high pressures by deep learning-driven ab initio simulations

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Boron phosphide (BP) is a (super)hard semiconductor constituted of light elements, which is promising for high demand applications at extreme conditions. We develop a deep machine learning potential (DP) for accurate atomistic simulations of the solid and liquid phases of BP as well as their transformations near the melting line. Our DP provides quantitative agreement with experimental and ab initio molecular dynamics data for structural and dynamic properties. The main contributions to structural changes at low pressures are made by the evolution of medium-range order in the B-subnetwork and, at high pressures, by the change of short-range order in the P-subnetwork. Such transformations exhibit an anomalous behavior of structural characteristics in the range of 12–15 GPa. DP-based simulations reveal that the $T_m(P)$ curve develops a maximum at $P = 13$ GPa, whereas experimental studies provide two separate branches of the melting curve, which demonstrate the opposite behavior [1].

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Computational and theoretical studies of aluminum K-line generation in 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. In recent experiments to generate K lines of aluminum in experiments with an explosive-magnetic generator (EMG) with a helical diameter of 200 mm, equipped by an explosive opening switch (EOS), the SXR pulse energy in the full spectrum was 71 kJ, in the quantum energy range above 1keV - 23 $\pm$ 2 kJ or 32 percent of the total radiation energy, which is comparable to the best results obtained at world electrophysical facilities with current rise times of 100 ns. This paper presents the verification results of the calculated radiation magnetohydrodynamic codes FLUX-3D and FLUX-rz for the generation of the aluminum K line in these experiments, as well as computational and theoretical studies of the SXR yield in different spectral ranges depending on the configuration of the load chamber and various types of load.

The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 ”Research in high and ultrahigh magnetic fields”

Methods of numerical and experimental studies of additive heat exchangers with Schwarz type surfaces

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Current achievements in the development of design, modeling, creation of experimental samples, conducting experiments and developing promising products of heat exchange devices using 3D printing with metals are presented. According to the conducted studies, Schwarz type P surfaces are promising [1] . Numerical calculations have been validated for these surfaces. The criterion dependences are obtained, which allow using traditional engineering techniques to carry out the computational design of a full-size heat exchanger. Technologies for manufacturing sealed samples of heat exchange matrices with Schwartz cells of type P from 5 mm and wall thickness from 0.2 mm to 8th grade surface purity have been developed. The tightness of the manufactured surfaces was confirmed by computed tomography.

[1] Svetlakov A, Gulimovskii I, Verbanov I and Maslova D 2024 *Journal of Engineering Physics and Thermophysics* **97**(3) 593–603

Conversion of computation density field to optical thicknesses in numerical simulation of experiments using synchrotron radiation

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The paper shows the predictive capabilities of the LEGAK technique [1, 2] for numerical estimation of synchrotron radiation intensity. Several algorithms for converting the calculated density field to optical thicknesses are considered. For two-dimensional axisymmetric problems, an algorithm based on the Abel transformation is used [3]. To demonstrate his work, numerical modeling of experiments on the investigation of the detonation propagation process in cylindrical explosive samples based on TATB was carried out [4]. For three-dimensional problems, an algorithm has been developed and implemented that allows varying the direction of the rays. The example of a test problem with a cube shows patterns of optical thicknesses in different directions of the rays. The implemented functionality makes it possible to describe in detail the transient processes during the initiation and propagation of detonation in explosives and can be used for the numerical study of fast-flowing gas dynamic processes.

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[3] Kozlovsky V 2006 *Information in pulsed radiography* (Snezhinsk: Publishing house of RFNC-VNIITF)

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Neural network implementation for optimization problem of the non-uniform duct shape

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There are situations in practical and research activities, when it‘s necessary to choose the most appropriate variant among a variety of alternatives using criteria called target function. In this case, we are talking about solving optimization problem.

The target function calculation in the non-uniform duct shape optimization is a resource-intensive procedure that requires CFD simulation. Feed forward neural network implementation for reducing optimization algorithm execution time approach is considered in this work. The neural network is used for estimation of the target function. The network was trained on dataset with the following structure: vector of unknowns (11 values) and vector of target values containing mathematical expectation and variance of Mach number distribution on axis and output. Adam algorithm [1] was used for training.

The target vector determination for the dataset was based on RANS-calculations results for gas flow using finite volume method in stationary formulation. The gas is perfect, viscous and thermally conductive. The channel wall was described using Bezier curve. The coordinates of reference points of the curve in a dimensionless form were used in the vector of unknowns.

The optimization problem was solved using differential evolution algorithm [2]. Numerical experiment shows that using this approach makes it possible to find optimal solution faster and with an accuracy comparable to using a complete gas dynamic calculation.

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Shell and fuel layer characterization of indirect–drive cryogenic target for laser thermonuclear fusion

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This paper presents the results of development control methods of parameters of the cryogenic target surfaces for laser thermonuclear fusion. Cryogenic target is spherical shell with a solid smooth, uniform in thickness hydrogen fuel layer, and its surfaces must meet high requirements: deviations from uniformity, concentricity, sphericity of the all target surfaces must be less than 1% [1]. The characterization method of the entire external surface of the shell using a confocal scanning is developed. The optical shadow and X-ray phase-contrast characterization methods of the cryogenic fuel layer are developed. A two-dimensional theoretical models of the visible radiation and X-ray beam propagation through a cryotarget by ray-tracing method are developed [2], [3]. The correlations between of the specific characteristics' positions on the images and the surfaces parameters of cryotarget were obtained for both optical shadow and X-ray phase-contrast methods. The programs have been developed for shadow and X-ray phase-contrast control of the solid cryolayer parameters.

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Structural, mechanical and vibrational properties of thaumasite from classical atomistic simulations

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Thaumasite plays an important role in cement chemistry as the primary cause of sulfate corrosion in Portland cement at low temperatures of less then 15 *extdegree*C. This mineral forms a solid solution with ettringite which is usually present in cementitious materials [1].

The ClayFF force field [2] has been originally developed for atomistic computer simulations of clay and cement materials. We have shown recently that the ClayFF force field, modified by the explicit inclusion of Metal-O-H angular bending terms into the parametrization, (ClayFF-MOH, [3]), not only reproduces accurately the crystallographic unit cell parameters of ettringite but at the same time, noticeably improves reproduction of the elastic properties of ettingite and its vibrational properties. Here we use the same ClayFF-MOH force field to study thaumasite by classical molecular dynamics simulations.

The research was funded by the HSE University Basic Research Program.

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Validation of the numerical solution for problem of thermal shock in graphite

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Parts made of carbon materials in rocket and space technology are subjected to intense thermal effects that precede their combustion, which leads to the initiation of stress waves (thermal shock) with their subsequent destruction. High heating rate and strong non-linear dependence of thermal conductivity on temperature due to porosity of carbon material determine the possibility of the effect of metastable heat localization in the blow-up regime. The evolution of the thermomechanical system is described by a system of differential equations of solid mechanics taking into account thermal expansion. Analytical solutions can be obtained for simplified formulations, so in practice numerical solutions are required, including those taking into account nonlinear thermophysical properties of materials. The most popular numerical methods in solid mechanics are the finite difference method and the finite element method. In this work, the formulation was implemented in the finite element analysis application package Comsol Multiphysics. The validation of the thermal problem was carried out on the basis of the analytical solution for the so-called fast diffusion equation $u_t = \Delta u^m/m$. A comparison with an analytical solution for the temperature dependence of thermal conductivity in the form of an inverse power dependence is presented.

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).

Automated processing of pressure sensor signals in air shock wave

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This paper proposes and implements a method for the automated processing of experimental data on the measurement of air shock wave (ASW) pressure generated by explosive charges. Such experiments are widely accepted and commonly used to determine the brisance of explosive compositions (see, for example, [1, 2]). The primary recorded parameters typically include the peak pressure at the shock wave front $P_{\max}$ the specific impulse of the compression phase of the shock wave I, and the duration of the compression phase τ_+. Due to the operational characteristics of pressure sensors in explosive shock waves, the values $P_{\max}$ they record are subject to significant measurement error. The proposed method for automated processing of pressure sensor signals involves approximating the time dependence of the ASW's specific impulse using an elementary function and subsequently differentiating this function. This approach allows for automatic reduction of errors in determining $P_{\max}$.

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Dynamics of gapped momentum states in viscoelastic media

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Gapped momentum states occur in non-equilibrium dynamic systems caused by wave and dissipative processes, so the study of this fundamental phenomenon represents interest for variety of nonlinear systems at extremal conditions (shocked solids and liquids, dusty plasma). Study of Gapped Momentum States during the propagation of shear waves in liquids has attracted considerable attention, revealing an incomplete frequency-wavenumber spectrum [1,2]. This implies a critical transition, leading to a qualitative change in the momentum transfer mechanism and system's properties. The main emphasis of this work lies in the exploration of Gapped Momentum States associated with wave propagation in viscoelastic media. Analytical solutions for the dispersion relations, based on the viscoelastic models of Kelvin-Voigt, Maxwell, the standard linear solid, and Kelvin-Voigt with fractional derivative, were studied. Conditions and criteria for the gap formation in momentum space were formulated for mentioned models. The relationship between phase and group velocity and wavenumber was visualized by plotting graphs using numerical data. Wave profiles were constructed, and the dynamics of wave propagation at various scales were demonstrated for specified momentum transfer mechanisms.

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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Modeling experimental conditions at the LINAC-200 electron accelerator in GEANT4

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In 2025, as part of the commissioning activities at the LINAC-200 linear electron accelerator, experiments are planned to study neutron generation processes using various converter targets. An electron beam with an energy of up to 20 MeV will be directed at targets made of different materials. The goal of the planned experiments is to create an experimental setup based on the linear accelerator for testing methods of neutron resonance spectroscopy and developing detectors designed to operate within the neutron spectral range of 0.5 eV to 18 MeV. At the first stage of the study, the selection of the optimal neutron-generating target is planned. For this purpose, simulations of neutron generation processes in targets made of tantalum, zinc, and cadmium were conducted in GEANT4 to evaluate their characteristics as neutron sources. For each target, the primary reactions responsible for neutron production were identified, the total neutron yield from the target surface in the direction of the electron beam propagation was determined, and a detailed list of isotopes formed in the target materials under specific irradiation exposure was compiled. Neutron energy spectra for each target within the specified energy range were also obtained.

Influence of quantum effects on wave propagation in a nonlinear medium

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Radiation photons can have different statistics. This fact makes the classical approach inapplicable in the general case. Squeezed light is an example. It is a challenging problem to study the propagation of such radiation in a nonlinear medium. One possible realization of this scenario is the propagation of the radiation in a set of Josephson junctions organized into a superconducting travelling wave parametric amplifier (TWPA). In such a system, driving mode decays into radiation in a wide frequency range. To describe this process, we offer a universal approach based on the Schwinger-Keldysh diagram technique in Nambu representation. We managed to derive kinetic equations for normal and anomalous photon occupation numbers of the modes of the generated radiation, as well as for the biases of the fields. Since these equations describe relations between the first and second moments of bosonic fields, a complete description of the kinetics of an arbitrary Gaussian state is formed. We show that in this picture the bosonic field biases play an important role. They can either suppress the parametric instability of the driving mode or, on the contrary, lead to the appearance of such instability depending on the shape of the spectrum of the medium and the driving frequency. This effect greatly affects the generation efficiency.

SPH modelling of ejecta from shock-loaded samples

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Mechanical processing of materials results in regular perturbations of the micrometer-sized surface. If the surface inhomogeneities are filled with particles, particle ejection and formation of microscopic cumulative jets are observed on such a surface under shock loading. This is a difficult task to study the spatial and temporal evolution under experimental conditions. It is also difficult to describe analytically because of the nonlinearity that occurs with intense impacts and large perturbations. On the other hand, details of jet formation can be obtained by hydrodynamic modeling. This problem is investigated in [1, 2].

The contact smoothed particle hydrodynamics (CSPH) method with MUSCL-type reconstruction of physical values at interparticle contacts is used for modeling. To increase accuracy the TKC method [3] is used.

Modeling of corundum particles ejection from the surface of an impact-loaded steel sample with a rough surface is performed.

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PANDA-NN: improved algorithm for contact angle determination in slit pores and interface classification

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Surface phenomena determine the behaviour of fluids in porous media and on wetted surfaces. Proper accounting of these phenomena is the basis of accurate continuum models [1]. The contact angle is a key quantity that quantitatively characterizes surface phenomena. Previously, a model was proposed that classifies the interface surfaces in slit pores [2] and offers a completely new approach for determining the contact angle from a one-dimensional density profile named PANDA [3]. An improved version of this algorithm is proposed, considering the presence of a non-zero wetting layer. The enhanced algorithm is validated on numerical data obtained from molecular dynamics calculations and demonstrates high accuracy. Additionally, a deep neural network based on the PointNet++ architecture [4] is trained to classify the interface surface based on the point cloud. These improvements have resulted in a fully complete algorithm with minimal hyperparameters.

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Electrohydrodynamic modeling of electrospray thrusters

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Small spacecraft require compact, less than 1U, and energy-efficient (5–100 W) propulsion systems. A promising solution is electrospray thrusters [1], which operate on the principle of emitting droplets and/or ions from the ionic liquid (IL) meniscus surface in an electric field, and followed by ion acceleration by electric field. A combined model, integrating analytical and numerical methods, is used to calculate electrospray thruster integral parameters. This study presents a numerical module that calculates the electrostatic field, the shape of the meniscus and droplets, and the velocities of the particles. The following values are supplied to input: thruster geometry, properties of the emitter material and IL, and voltage between cathodes. The formation of the Taylor cone and the subsequent droplet/ion mode at the emitter needle is calculated using a 2D axisymmetric electrohydrodynamic leaky dielectric model [2]. The electrostatic field is calculated from Poisson's equation, and the charge conservation law is solved alongside the Navier-Stokes equation for flow field and charge distribution. The Volume-of-Fluid (VOF) method is used to capture the interface between liquid and vacuum. The hydrodynamic equations are solved in OpenFOAM using the finite volume method, while Poisson's equation is solved in MFEM using the finite element method. To verify and validate the model, the meniscus shape was computed and compared with the data underlying the study [3]. The module will be further expanded and improved by incorporating particle motion to predict the divergence angle and the extractor surface impingement rate.

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Application of computer vision technologies for plasma flow diagnostics

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Pulsed plasma accelerators are devices that accelerate plasma under the action of ponderomotor forces, which can be used as a propulsion system for small spacecraft along with such analogues as [1], [2]. To use an IPU as a remote control, it is necessary to conduct a number of tests to determine the geometric characteristics of the plasma flow, such as: the angle of divergence of the flow and the angle of deflection of the flow, since it is necessary to determine the direction of the thrust vector. In this paper, the possibilities of detecting and classifying plasma formations using AI methods are demonstrated. Based on the resulting data array, a convolutional neural network was trained [3], which allows detecting the plasma flow on the frames and classifying two separate areas in it. The Object detection model has been trained to detect the plasma flow and classify its individual regions. A code module has also been prepared along with a user interface for remote operation with the experimental stand, in order to determine the angle of flow divergence and the angle of its deviation from the horizontal axis of the engine in real time. The work was performed at the unique scientific installation (UNU) "Puchok-M" of the Bauman Moscow State Technical University, with the support of the Ministry of Science and Higher Education of the Russian Federation under the state assignment FSFN-2024-0007.

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An approach to numerical modeling of hydrogen-air-dust mixture combustion

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Based on one-dimensional calculations using detailed chemical kinetics of hydrogen combustion and single-stage chemical kinetics of tungsten dust oxidation by oxygen and steam, the combustion of hydrogen-air-dust mixtures is considered.
Based on the calculations performed, two main combustion modes are distinguished: the one stage combustion mode and the two stage combustion mode.
In the first case, the gas-dust mixture burns as a single whole, while in the second, the ignition of the dust phase occurs with a delay relative to the combustion of the gas mixture.
For each of the cases, an approach to numerical modeling is proposed for use in large-scale combustion problems.

Determination of equilibrium concentrations of H and H_2 in Pb melt using *ab initio* metadynamics calculations

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The deployment of fast neutron reactors for closing the nuclear fuel cycle is considered promising for nuclear energy. In these reactors, heavy metal coolants, particularly lead, are used as the primary loop coolant. Hydrogen can enter the primary loop either during cleaning – when hydrogen is introduced into the coolant volume to bind oxygen and dissolve solid-phase PbO oxides – or as part of water molecules in the heat exchange zone between the primary and secondary loops. Since hydrogen actively binds with oxygen, controlling its state in the coolant volume is essential [1].

Ab initio molecular dynamics (MD) calculations allow the study of the behavior of individual atoms and molecules in liquid lead [2]. For our calculations, we use the VASP software package. To determine the thermodynamically equilibrium concentrations of hydrogen atoms and molecules in the lead melt, we calculate the free energy of molecule formation in the melt. The free energy is computed using the metadynamics simulation approach [3], which involves adding an adaptive potential to the MD simulation. For a specific temperature, the thermodynamically equilibrium concentrations of molecular H_2 and atomic H hydrogen impurities in the lead melt is obtained.

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Impact of magnetism on Fe phase diagram under extreme conditions

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Iron is a major component of the cores of the Earth and inhabited exoplanets. Its phase diagram at extreme pressures and temperatures is the subject of extensive debate. While recent experiments provide the evidence for the stability of the body-centered cubic (bcc) phase, several theoretical studies point to the stability (even though marginal) of the hexagonal close–packed phase. None of those studies considered the itinerant magnetism of iron at extreme conditions. We compute the high-pressure phase diagram of Fe using density functional theory-based molecular dynamics (DFT MD) in which the paramagnetic nature of Fe is treated within the model of thermally induced longitudinal spin fluctuations (LSF). The LSF DFT MD favors bcc phase stability. Two-phase large scale simulations with quantum accurate machine learning potentials provide us with both melting and hcp-bcc phase boundaries. The computed phase diagram agrees with most of the experimental data and solves most of the numerous controversies. We conclude that the account for magnetism results in the new physics of iron under extreme conditions and brings the theory in agreement with experiment and seismic data. We expect that the approach we use can be applied for other metals where itinerant magnetism is important.

Investigation of methods for removing the boundary layer from the surface of a streamlined plate

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The formation of a substantial boundary layer can negatively impact flow parameters, leading to separation zones. This may result in a reduction in flow momentum due to the increase in the thickness of the displaced boundary layer, adversely affecting the efficiency of various systems. To address this issue, drain holes are utilized to eliminate excess boundary layers. The significance of this challenge has been demonstrated in various studies, such as [1–3]. Given the diverse shapes and methods of placement of drain holes, optimizing their arrangement for efficient boundary layer drainage is essential. A study on this subject was conducted in [4], examining the influence of gap width on separation zone size based on experimental data.

To conduct a more detailed analysis of the configuration and placement impact of the drainage ports on the thickness of the displaced boundary layer and loss of liquid momentum, a series of three-dimensional (3D) numerical simulations were conducted. The variables that were altered included the linear dimensions, depth, and relative positioning of the drainage orifices, with flow parameters being assessed. Software packages utilizing gas dynamics modelling, employing the resolution of the Reynolds-averaged Navier-Stokes equations through the finite volume approach, were employed to address this issue.

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Method for determining of Jones–Wilkins–Lee equation parameters using the cylinder test results

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The paper presents a method for determining the parameters of the Jones–Wilkins–Lee equation of state (EOS) for detonation products of explosives using the results of the cylinder-test experiment. Three types of approximation functions are used to fit the experimental data and the optimal one with a minimum error value is selected. The search for the EOS parameters in this technique is carried out using the optimization method in three-dimensional space (R_1, R_2, ω) with the determination of remaining parameters (A, B, C) from the linear equations, which, in comparison with optimization in six-dimensional space $(A, B, C, R_1, R_2, \omega)$, has a faster convergence. The method ensures the realization of physical restrictions on the EOS parameters. To verify the EOS parameters, mathematical modeling of test problems was carried out with determined and reference EOS parameters, e.g., [1]. Mathematical modeling is based on solving the system of continuous medium mechanic equations in Euler coordinates to describe gas-dynamic flows of detonation products and in Lagrangian coordinates to describe elastic-plastic flows in the material of a cylindrical tube. The results are in good agreement with the experimental data.

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5. Physics of Low Temperature Plasma

Evolution of active Brownian motors in plasma, viscous fluid and superfluid helium

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In plasma, or viscous fluid, or superfluid helium, complex motion of micron-sized Brownian particles can be observed when the particles absorb the energy of laser radiation and convert it into motion energy. Such particles can be considered as active Brownian motors whose motion is controlled by radiation, and the mechanism of active Brownian motion itself is associated with photo- or thermophoresis (in plasma and liquid), or with the appearance of quantum turbulence (in superfluid helium). Active Brownian motors are able to obtain energy from external sources, store it and spend it on their own motion in the medium, which can lead to their self-organization and evolution.

The active Brownian motion of light-absorbing and strongly interacting particles far from equilibrium suspended in a gas discharge under laser irradiation has been studied, where the nature and intensity of the active motion depend on the radiation exposure. Emulsions of complex composition were experimentally obtained and their dynamics initiated by laser irradiation was investigated. Active Brownian motion and the evolution of structures due to quantum effects were experimentally observed for the first time for micron-sized particles levitating in superfluid helium.

Influence of buffer gas pressure on the dynamics of active Brownian particle in RF discharge plasma

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An experiment was conducted to study the evolution of active Brownian systems [1]. A voltage with a frequency of 13.56 MHz was applied to an RF electrode with a parabolic shape cavity in argon, creating a RF discharge. Spherical plastic particles with partial molybdenum coating were injected into the near-electrode zone. The particles were charged by electron and ion fluxes and levitated above the center of the electrode. Upon illumination with a laser, a temperature gradient was formed on the particle surface, resulting in a radiometric force whose direction changed stochastically due to rotational diffusion. The particle motion was recorded using a high-frequency video camera. During the experiment, the buffer gas pressure in the discharge was varied (1 Pa, 10 Pa, and 30 Pa), influencing the regime of motion of the active particle. The overdamped, underdamped and crossover regimes of motion were obtained. The dependence of the mean first-passage time dynamic entropy [2] on the coarsening parameter, the value of the fractal dimension of the particle trajectories, and its localization area were obtained. The crossover region between ballistic and diffusion regimes of the MFPT function from the buffer gas pressure is investigated.

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Experimental study of spoke instability in reflex discharge with thermionic cathode using a high-speed camera

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This work presents the results of a study of the spoke instability [1] occurring in crossed ExB fields in a reflex discharge with thermionic cathode [2]. This instability, also known as the Simon-Hoh instability [3, 4], is a rotating sector with a changed plasma potential and broken plasma quasi-neutrality. During the experiment, argon under a pressure of 0.3 mTorr was pumped into a cylindrical chamber about 2 m long and 86 cm in diameter, the magnetic field was 1400 G, and the radial electric field was 10-15 V/cm. Measurements of luminescence intensity were performed using an Evercam 3000-16-M high-speed camera with maximum speed 56 900 frames per second. Using Fourier analysis, it was found that the electron beam emerging from the thermionic cathode rotates. The rotation radius is about 1 cm, the frequency is 10-15 kHz, which coincides with the spoke instability frequency previously measured by floating probes [2]. As a result of the study, the presence of the spoke instability in the main volume of the discharge was also optically confirmed.

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Dynamics of an inhomogeneously heated Brownian particle in a harmonic trap

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A mathematical model is developed to describe the dynamics of active Brownian particles in rarefied gases and complex plasmas. The model takes into account the main features: the presence of an active force associated with non-uniform heating of the particle surface, translational and rotational inertia, inhomogeneous distribution of the particle mass due to the presence of a light-absorbing coating on one of the halves of the particle. A numerical simulation of the dynamics of an active Brownian particle with center of mass displacement in the confinement force field of the trap is performed. The obtained particle trajectories correspond to those observed in real experiments with Janus particles. A comparison of the results at different ratios of the particle surface temperature and a comparison of the dynamics of a particle with unshifted and shifted center of mass are performed. A significant influence of the inhomogeneous heating of the surface on the motion character of an active Brownian particle in the free-molecular regime in the presence of a confining force field of the trap is obtained.

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Physical characteristics of chemically active plasma based on volatile halides in the processes of obtaining highly pure isotopically enriched substances

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Currently, interest in high-purity Si, B, Mo, and Ge with modified isotopic composition in crystalline and nanodispersed states has increased significantly. It is planned to create a quantum computer based on 28Si and 29Si [1]. Detectors based on 76Ge and 73Ge are needed to search for "dark matter" and study double beta decay [2]. To optimize the plasma-chemical processes for obtaining the specified target products, it is necessary to study the internal physical parameters of the plasma.

To determine the parameters of cold nonequilibrium plasma by contact and contactless methods, diagnostics of nonequilibrium chemically active plasma in mixtures of volatile halides of Si, Ge, B and Mo with H2 and Ar were carried out. Methods of thermodynamic and gas-dynamic analysis, as well as emission spectroscopy, were applied to thermal gas discharges. The main parameters of gas discharges, as well as the main chemical reactions affecting the formation of target products, were determined.

The work was supported by the state assignment of the Ministry of Science and Higher Education of the Russian Federation, topic No. 0095-2019-0008.

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Dynamic properties of a single active Brownian particle in near electrode layer HF discharge

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The dynamics and self-organization of active colloids are currently a focus of attention for many researchers worldwide. Active colloidal particles can convert environmental energy into motion. The combination of collective interactions among them and positive energy flow from the environment enables active systems to exhibit complex behavior and self-organization [1–3], similar to living organisms.
We present results of an experiment on a single active Brownian particle in RF discharge. The active particles used in the study were calibrated plastic spheres with a diameter of 11.56 μm, partially coated with molybdenum. When the particle is illuminated by a laser, a radiometric force occurs [4], whose direction changes stochastically due to rotational diffusion. The laser power in the experiment varied from 50 mW to 1500 mW.
For each case, the particle's trajectory, kinetic energy, mean squared displacement, and chirality parameter (average sign of the sine of the angle between the particle's velocities at consecutive trajectory points) were obtained. The dependencies of these parameters on laser power were investigated.
This work was supported by the Russian Science Foundation (project no. 24-12-00345).

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Clusterization of defects and crystallites in a 2D Yukawa liquid

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Various properties of solid-like clusters (i.e., clusters consisting of particles with six nearest neighbors) in a two dimensional Yukawa liquid have been considered for the first time in a wide temperature range starting from the melting temperature [1] . With increasing temperature, the concentration of crystal particles (which noticeably prevail in a melt) decreases slowly, while the defect concentration increases, which results in the formation of large clusters consisting of defects and in the degradation of large crystal clusters in the considered two-dimensional system. Their characteristic size and shape change drastically in a narrow temperature range. The comparative analysis of crystal clusters and clusters consisting of topological defects has been performed. Finally, we discuss how universal the clusters properties of dense 2D liquids are.

[1] Klumov B A 2024 *JETP Letters* **120** 650–654 ISSN 1090-6487 URL http://dx.doi.org/10.1134/S0021364024603403

Coulomb and van der Waals interactions of nanoparticles in plasma

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The electrostatic interaction of nanoparticles caused by the overlap of double electric layers and the van der Waals interaction caused by quantum and thermodynamic fluctuations of electromagnetic fields are considered in electrolytes [1, 2] and dusty plasmas [3]. An exact solution to the problem is obtained for both identical particles and particles of very different sizes. For the van der Waals interaction, screening of static fluctuations and the retardation of electromagnetic fields for the dispersion part of the interaction are taken into account. The predominance of the van der Waals force over the force of screened electrostatic repulsion was found at high electrolyte concentrations in the range from 10^{-2} to 10^{-3} mol/l for both small and large interparticle distances. In dusty plasmas, no predominance of the van der Waals force over the screened electrostatic force was found at large interparticle distances [3].
This work is devoted to a more thorough study of the interaction forces in dusty plasmas and electrolytes using a numerically stable method for calculating the geometric factor, taking into account the retardation of the electromagnetic field. The studies were conducted in electrolytes with different dielectric permittivity of the solution and in dusty plasma with vacuum dielectric permittivity while varying the Debye screening constant, charge (surface potential) and radius of nanoparticles over a wide range.

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Experimental study of diffuse vacuum arc plasma parameters by optical spectra

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For plasma separation technology, it is necessary to create a source that generates a flow of single-ionized plasma with a high ionization degree [1]. Such requirements can be met by a diffuse vacuum arc [2]. This research is devoted to this type of discharge with a cathode made of thermionic gadolinium in an axial magnetic field.
The discharge was initiated in a vacuum chamber at residual gas pressure of $\sim 10^{-5}$ Torr. A uniform magnetic field in the discharge gap was created by Helmholz coils. The cathode material was placed in a molibdenum crucible, which was heated using electron beam heating. During the experiment, power supplied to the cathode reached 2 kW, while the crucible temperature varied from 1800 to 2000 K, discharge voltage from 5 to 30 V. Discharge current varied from 30 to 50 A, external magnetic field from 0 to 500 G.
This study considers the influence of discharge voltage and external magnetic field on charge composition of generated plasma, electron temperature and ionization degree. The radial distribution of electron tempeture was also obtained.
The study was supported by Russian Science Foundation (No. 23-72-10073), https://rscf.ru/en/project/23-72-10073/

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Investigation of the conversion from condensed CeO_2 to vapour flow and its deposition for plasma separation applications

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One of the methods for processing spent nuclear fuel (SNF) is plasma mass separation, which involves three main stages: the conversion of a solid or gas substance into a plasma; the separation of charged particles in space; and the deposition of separated streams [1]. The technological requirement for the final stage of separation is to create conditions that ensure sticking efficiency which approaching 100% [2]. This paper presents the results of studying the conversion of CeO_2 samples, a material that can simulate the primary component of SNF (UO_2), into a vapour flow by using a laser method, followed by its deposition on different substrates. The experiments were carried out on samples with an optimal mass ratio between vapour and coarse phase. Data on the sputtered CeO_2 coatings obtained using a profilometer provided information about directional diagram of the vapour flow and sticking coefficients on the substrates.

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Unified data set for transport and radiation properties of low-temperature plasma of noble gases

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Noble gases have a very wide use in industry and science, from lasers and light sources to different types of discharge plasma. Knowledge of transport and radiation properties of noble gases is necessary for predictive modelling of chemically and optically active plasma. This work presents the methodology and detailed set of data for transport and radiation properties of noble gases (He, Ne, Ar, Kr, Xe) and their mixtures in wide range of temperatures (T=100-50000 K) and pressures (P=0.1-300 bar). Transport coefficients were calculated in the assumption of the local thermal and chemical equilibrium (LTE) in the framework of Chapman-Enskog theory. All coefficients were calculated in the second approximation by the accurate formulas of Chapman-Enskog theory. Effective thermal conductivity was calculated as a sum of translational thermal conductivity and reactive one, which was obtained from the advanced version of Butler-Brokaw formula. Absorption coefficients of noble gases plasma were calculated based on data set of electronic energy levels, transition probabilities of atoms, potential energy curves and transition dipole moments of excimers. A numerical realization of described above was implemented in the Fluid Workbench program suit.

Generation of radio emission in the centimeter range in a laboratory pulsed megavolt discharge at the stage of growth and collision of streamers

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The paper demonstrates a radio interferometry system based on four ultra-broadband antennas, which makes it possible to localize microwave radiation sources in an extended (up to 1 m) high-voltage (up to 1.2 MV) laboratory spark discharge with centimeter accuracy and to investigate the temporal and spatial characteristics of microwave and their correlation with discharge structures [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 bursts 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 emissions were localized. Our study shows a close relationship between radio emission and the intensive development and reproduction of multiple streamers of opposite polarity in the dischargecite [2] [3].
The work was carried out with the financial support of the Russian Science Foundation (grant 23-19-00524).

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Capabilities of the PmL device for plasma-dust sensing of various space objects

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Space experiments on contact detection of dust for various extraterrestrial objects were launched in the Apollo 17 mission and continue to this day. LEAM (Lunar Ejecta and Meteorite), PUMA (Particles dUst Mass Analyzer), GIADA (Grain Impact Analyzer and Dust Accumulator), SP-1/METEOR (dust counter), LDEX (Lunar Dust Experiment) and others are very interesting dust instruments aboard famous space missions. The PmL device was created to monitor plasma-dust dynamics near the lunar surface. In the Luna-25 mission, the device worked in a transfer orbit for more than an hour, obtaining not only calibration data, but also real measurements of the dust and plasma environment for two flyby zones. The ability of the PmL to measure the pulses and charges of dust particles is not limited by a deep vacuum, and the design capabilities make it possible to obtain scientific data from the PmL instrument on Mars, in terrestrial conditions and in outer space. The range of measurement of the momentum of dust particles, starting from the minimum - fractions of a picoNewton per second, extends to more than 6 orders of magnitude with the possibility of registering their charge from 1500 electron per dust particle. It is especially productive to use PmL on the surface of the Moon as a dusty-plasma device, since in addition to detecting dust particles flying near the lander, it can diagnose changes in electric fields in the landing area using the Langmuir probe.

Experimental and numerical investigation of structural transitions in a quasi-two-dimensional system of colloidal active particles in plasma

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Calculated results are presented for experimental investigation of structural transitions in a quasi-two-dimensional system of dusty active particles in comparison with numerical investigation of appropriate transitions in model system of passive and active particles. Experiment was carried out with MF (melamine formaldehyde) particles in RF discharge and transitions were observed by increasing laser power. The simulations were performed in LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator). The particles affected by the radiometric force were chosen as the model of active particles. In this study, we discuss and compare features of melting the systems under consideration. Various melting criteria are considered, such as the dynamic Lindemann criterion [1], the criterion based on cumulative two-body entropy [2] and the analysis of defect clusters. A significant difference in the melting scenario of active and passive particle systems has been revealed. This work was supported by the Russian Science Foundation (project no. 24-22-00130).

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[2] Klumov B A K S A *Results in Physics* **17**(103020)

Thermodynamic limit of non-degenerate hydrogen plasma using quasi-classical molecular dynamics

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In this study, we perform a quasi-classical molecular simulation of a hydrogen plasma in the weak degeneracy regime over a wide range of coupling parameters. The simulations utilize the improved Kelbg pseudopotential [1], which incorporates the quantum uncertainty principle, provides an accurate treatment of bound state formation, and enforces the Pauli exclusion principle to prevent same-spin electrons from occupying identical states. Furthermore, we employ the improved Kelbg-AAE pseudopotential using KelbgLIP [2], which accurately accounts for interactions with all periodic images.

Our findings are compared with Path Integral Monte Carlo simulations by Filinov and Bonitz [3]. We analyze the stability of hydrogen plasma, addressing the challenge of cluster formation at temperatures below 50 kK [1], and explore the dependence of equilibrium energy on the number of particles. The results confirm the effectiveness of the pseudopotential approach in describing systems with strong long-range interactions.

The work is supported by the Russian Science Foundation (project No. 24-19-00746).

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Plasma discharge under the effect of intensive ultrasound and its application for plasma-chemical synthesis of functional nanomaterials

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In the work, plasma-chemical processes determined by the combined effect of thermally nonequilibrium low-temperature plasma and intensive ultrasonic vibrations in the cavitation regime in liquid-phase media were studied. This method of plasma-chemical synthesis of nanomaterials is of considerable interest and has advantages for creating new nanosized materials with specific properties, since it allows for targeted variation of the electrophysical and acoustic characteristics of the process during plasma-chemical reactions. A practical consequence of solving this problem is the creation of a method for the targeted synthesis of valuable substances. A distinctive feature and significant advantage of this method is that the simultaneous effect of thermally nonequilibrium plasma and ultrasonic cavitation on the reaction zone leads to the emergence of conditions that are unattainable in other cases and causes reactions to occur at a high local concentration of energy and active particles. So it is possible to synthesize nanoparticles of metals and their oxides of various compositions, while the size of the primary nanoparticles was at the level of 2–80 nm depending on the material. Further on, it was shown that nanoparticles of various compositions synthesized in such conditions have an activated surface with a large number of uncompensated bonds and defects as a result of the action of intensive ultrasound. Thus these particles are capable of effective interaction with organic and inorganic compounds, matrices, etc, which allows creating new hybrid organic-inorganic composite materials as well as polymer nanocomposites. This work has been financially supported by the Russian Science Foundation, project No. 23-19-00540.

Accelerated self-consistent charge calculations for simulating the dynamics of complex plasma structures

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The consideration of charges on dust particles is essential for accurately modeling various dust systems, including the simulation of chain structures formed by these particles. However, direct self-consistent simulations of dust particle charges alongside their dynamics demand substantial computational resources, even with the aid of modern supercomputers and optimization techniques. This challenge becomes particularly pronounced when attempting to obtain dynamic characteristics of dust structures, such as vibration spectra. In this study, we introduce a novel method that significantly accelerates the self-consistent calculation of dust particle charges during the simulation of their dynamics. Our approach relies on a pre-computed relationship between the charge of a dust particle and the positions and charges of neighboring particles. The charge calculations are carried out using our developed software, OpenDust [1, 2], which facilitates efficient and accurate simulations in multi-level dust dynamics.

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Excitation of a closed current loop in plasma during radial breakdown of a dielectric surface in an axisymmetric geometry

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A closed loop with a current in the plasma is called a compact torus or FRC (Field Reversed Configuration). Tori can be accelerated and compressed by external magnetic fields in thermonuclear colliders and electric rocket engines. A new method for forming compact tori in inductive energy storage devices was proposed. This method demonstrated high efficiency of magnetic energy conversion in the accumulator - up to 70 percent of the stored energy is transferred to the plasmoid, the current reached several tens of kiloamperes with a plasmoid diameter of 30 cm, and its speed was 40 km/sec. Two plasmoids accelerated towards each other produced a plasma temperature of over 1 keV at the collision point and a soft X-ray radiation duration of about one microsecond, which is three orders of magnitude longer than the duration of such radiation in Z,X-pinch and plasma focus installations. This demonstrates the real possibility of implementing inertial nuclear fusion. However, inductive accumulators require current interrupters. In our paper [1], we explained the structure of the current during the explosion of thin conductors with the appearance of striations and closed current turns around the exploding conductor. In continuation of the topic, the formation of a compact torus was shown during an ablation discharge on the surface of dielectrics in an flat axisymmetric geometry on a new installation like plasma focus.

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Investigation of the interaction of laser radiation with shock-compressed dense krypton plasma

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The correct description of collision processes in a partially ionized dense plasma is possible only on the basis of sufficient information about its optical properties and the study of the optics of a dynamic object is a powerful research tool, since optical properties are very sensitive to changes in the electronic subsystem of the medium.
The results of new experiments on opto-polarizing properties of an explosively driven dense krypton plasmas are presented. The optics of shock-compressed plasma were studied by the method of oblique probing. The measurements of polarized reflectivity coefficients of strongly correlated dense plasma have been carried out at incident angles up to $\theta = 65^\circ$ simultaneously for s- and p-polarization using laser light of frequency $\nu_{\rm las} = 2.83 \times 10^{14}$ s^{-1}. The experiments were performed at the plasma density $\rho = 1.7$ g/cm^3 and $\rho = 1.95$ g/cm^3, pressure up to $P = 12$ GPa and temperature up to $T = 29000$ K. The composition and thermodynamic parameters of the plasma were determined using the modified Saha IV code [1].

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The influence of the corona electrode material on its modification processes in a barrier discharge in air

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Dielectric Barrier discharge (DBD) is a low-current high-pressure discharge initiated in an electrode system with a dielectric barrier. Long-term operation of the discharge leads to modification of the corona electrode. Changes in the morphology of the electrode edge affect the uniformity of the DBD and its electrical characteristics. Electrode modification occurs as a result of competing mechanisms of erosive cleaning in the cathode layer and the formation of oxides on electrode edge [1].

The aim of this work is to study the effect of the corona electrode material on the modification processes. A comparison was made of the structure and dynamics of the discharge power during continuous operation for 200 min on electrodes made of Cu, Ni, Mo and Al. Discharge on Cu and Ni electrodes has a high degree of heterogeneity along the electrode span. In the case of electrodes made of Al and Mo, the discharge looks like a diffuse glow region. When modifying electrodes made of Cu and Mo, there is a noticeable increase in the power dissipated in the discharge, while in the case of electrodes made of Ni and Al, there is a decrease. The reason for the different behavior of the electrodes during modification in the discharge is the binding energy of the oxides and their electrical conductivity.

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[1] Selivonin I V, Lazukin A V, Moralev I A and Krivov S A 2018 *Plasma Sources Sci. Technol.* **27**(8) 085003

Wake effect on motion of the different size microparticles in plasma sheath

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Recently, interest in systems in which the symmetry of interaction is violated has increased. An example of such a system is a complex plasma. The ion flow is modulated by a negatively charged microparticle so that a region of increased ion concentration, an ion wake, arises behind it [1]. Neighboring microparticles interact both directly with the first and with the ion wake. In addition, the charge of a microparticle within the ion wake decreases due to extra ion flow to its surface [2]. This paper presents studies of the motion of microparticles of two sizes in the near-electrode layer of a high-frequency discharge. First, a flat layer of particles with a diameter of 10.41 μ was formed. A small amount of 7.17 μ diameter particles was then added. The motion of a single smaller microparticle above a layer of larger microparticles, as well as microparticles in this layer, was studied using three-dimensional diagnostics by binocular vision [3]. The microparticle of the lower layer, located directly under the upper particle, has descended by 0.2 mm due to the decrease in charge. The upper particle performed a continuous rotational motion. The microparticle of the lower layer, nearest to the upper one, follows the movement of the upper particle with some delay. Analysis of this motion, as well as oscillations of microparticles in the vertical direction, allows us estimate the force of attraction to the ion wake and the reduction in the charge of the lower particle, which reached 7%.

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Electrical breakdown in pulsed electric field in water-oil system

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Development of electrical breakdown across the interface between water and transformer oil in a pulsed electric field is studied experimentally and by mathematical modeling. The discharge develops through the growth of a water cone in the oil towards the high-voltage electrode in the studied range of applied voltage, which is below oil breakdown voltage for a given layer thickness. Depending on water conductivity and amplitude of applied voltage and after the cone reaches the high-voltage electrode 1) electrical current can flow without plasma formation, 2) electrical current can cause plasma onset through thermal mechanism of breakdown, or 3) plasma channel can appear through the water droplets before the cone touches HV electrode due to water jet at the cone tip. At long pulse duration and voltages insufficient for short circuiting, the water cone occupies an equilibrium state somewhere inside the gap. Its height is independent of pulse duration and determined only by voltage amplitude. At voltages sufficient for gap closure, the closing time decreases sharply with increasing voltage. Such nonlinear behavior is attributed to the fact an electrostatic force originates from the spatial inhomogeneity of the Maxwellian stress tensor and is determined by the values of the second derivatives of the potential. The performed mathematical modeling showed the main part of this inhomogeneity occupies a thin layer the interface between two liquids. The force determined by the divergence of the Maxwell tensor is contributed by the spatial variation of the square of the electric field (energy density) rather than by the change in ε, although they are related. Thus, the thin layer where the force acts is not located in the middle of the interface as might be expected, but is above the area of the maximum ϕ and ε gradients — in the liquid with smaller ε.

Diffusion of the magnetic field in the explosion of flat conductors

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The formation, expansion of plasma and the passage of a wave nonlinear diffusion of a magnetic field on a terawatt generator MIG (2.5 MA, 100 ns) were studied during a nanosecond explosion of flat aluminum conductors with perforation in the form of round holes. The exit of the nonlinear magnetic field diffusion wave to the boundaries of the holes was studied by the glow of the formed plasma. The density of the substance in this plasma was estimated. Flat aluminum conductors with a thickness of 100 μm and a width of 5 mm were used in the experiments. The images obtained in the visible range showed that due to the amplification of the magnetic field on the end faces of the flat conductor, they explode and form plasma with the development of instabilities. In this case, there is practically no expansion of the conductor. In the holes, plasma is formed from the direction of the side edges and the hole expands in their direction. Along the conductor in the direction of current flow, the size of the hole remained unchanged until the maximum current. A luminous halo was recorded around the hole in the direction of the side edges. It indicates the meeting point of the incident and reflected pressure wave accompanying the field diffusion wave. The propagation velocity of the field diffusion wave in the flat conductor was measured. The wave under these conditions propagates at a speed of 50 km/sec. Based on X-ray images of flat loads the density of the substance in the plasma at the boundaries of the conductor and inside the holes was estimated.

Macroscopic quantum shell effects in submicron hemispherical clusters

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The existence of macroscopic shell structure of submicron metal clusters is known for several decades [1]. Since the most studies provide theoretical analysis for clusters of spherical shape, the electron density inhomogeneities caused by shell effects [2] are spherically symmetric and do not provide long range electrostatic fields. However, similar shell structure should exist in a hemispherical cluster which conserves the closed periodic orbits of electrons, but not the spherical symmetry of electron distribution. As a result, we demonstrate that a strong electrostatic field exists in the vicinity of the flat surface of an isolated, uncharged metal nanocluster of hemispherical shape using modern approaches for electronic structure evaluation. This physical phenomenon is a consequence of the large-scale spatial inhomogeneity in distribution of electrons related to quantum shell effects in submicron metal clusters, which may find numerous applications in various fields of science and technology.

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Numerical model of the source of shock wave excitation in a high-pressure gas-discharge chamber under the influence of a high-current discharge

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A model of the source of shock wave excitation in a gas-discharge cylindrical chamber filled with hydrogen at a high pressure of $0.5 \div 32$ MPa is presented. The source of perturbation is interelectrode breakdown by a megaampere-class current with a rise rate 10^{10} A/s [1]. It is defined that the discharge produces a plasma channel with separated boundary of envirements [2]. In such a representation, the plasma channel can be described by a wire-conductor with time-dependent conductivity. This allows us to estimate the electric field strength in the discharge and to refine the model of energy release in the discharge channel [3]. The calculation of the electric field and conductivity in the plasma channel allows us to improve the accuracy of the description of the energy release source for the problem of shock wave propagation in a cylindrical discharge chamber when discharging with megaampere-class currents.
The study was financially supported by the Russian Science Foundation (project 25-29-00751, https://rscf.ru/en/project/25-29-00751/).

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Formation of active Brownian particle systems in DC glow discharge plasma

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Open dissipative systems far from equilibrium are the object of study of various processes, including self-organisation and evolution [1]. One of the examples of such systems is the system of active Brownian particles in gas-discharge plasma, which can transfer energy and matter to the medium [2, 3].

The formation of active Brownian particles in the plasma of a glow DC discharge has been studied experimentally. The possibility of synthesis of particles from different materials (copper, nickel and aluminium) of the sputtering cathode was shown. The dependence of particle characteristics on the parameters of their formation in the gas-discharge tube has been found. The mechanisms of particle synthesis varied in the volume of the setup. Samples of synthesised particles were found in different parts of the experimental system, which is characteristic in the case of metal ion transport and agglomeration mechanism. Based on SEM microscopy and EDS analysis techniques, the properties of the synthesised particles were studied. The synthesised metal particles, able to convert the laser energy into their own motion, were active Brownian and formed extended dust structures in the positive column of a glow DC discharge.

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On the recombination in ultracold plasma trapped in an optical ponderomotive trap

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Inhomogeneous oscillating electric field exerts a force on a charged particle—the ponderomotive force. Charged particles are repelled from a region of high field intensity. In this paper an ultracold plasma trapped in the optical frequency field is studied. Trapping is achieved by using a hollow laser beam which has zero field amplitude in the beam's center and surrounds the plasma by high field region. We investigate how the trapping field changes the three-body recombination in the plasma using molecular dynamics calculations. Dependencies of the recombination rate on the trapping potential depth and inhomogeneity are discussed. Simple analytical model for the recombination in a ponderomotive trap is proposed.

The research is supported by the Russian Science Foundation (project No. 23-72-10031).

Technique for three-dimensional diagnostics of microparticles in colloidal plasmas

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In studies of active systems, diagnostics of microparticle dynamics plays an important role. In some cases, such as two-dimensional melting studies [1], it is often sufficient to use simple two- dimensional diagnostics. In this case, the system of microparticles is simply recorded by a video camera located perpendicular to the plane of the monolayer. In more complicated cases, such as investigation of the dynamics of three-dimensional systems of active particles levitating in the strata of the DC discharge [2], it is necessary to use three-dimensional diagnostics.
This work provides a review of known methods for two-dimensional and three-dimensional diagnostics of microparticles. The recent results on the study of active colloidal plasma using these techniques are presented, such as an analysis of the root-mean-square displacements of active Brownian particles, phonon spectra in a two-layer structure consisting of particles of different sizes, and structural instability accompanied by a transition to a square lattice in a quasi-two-dimensional plasma crystal [3].

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Kelbg pseudopotential with Ewald summation technique for strongly coupled weakly degenerate hydrogen plasma simulations

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The solution of the Blöch equation in first-order perturbation theory [1] yields a pseudopotential for simulating the thermodynamic properties of two-component Coulomb systems. The Ewald potential that accounts for the Coulomb long-range interaction has a complex form, which prevents finding an analytical solution. The angular-averaged Ewald potential (AAEP) has a very simple form [2], so a pseudopotential can be obtained in direct analytic form [3]. This pseudopotential can be used to perform quasi-classical simulations of the plasma's thermodynamic properties [4]. This work provides a step-by-step derivation of the Kelbg-AAE pseudopotential for a two-component Coulomb system [2]. Solving the Blöch equation with the AAEP yields an improved Kelbg pseudopotential [4], which accounts for the Coulomb long-range electron-proton interaction in hydrogen plasma [5]. Similarly, we calculate a pseudopotential for the interaction between electrons, accounting for its spin. In order to examine strong coupling regimes at low degeneracy, it is important to introduce effective electron repulsion to account for the Pauli exclusion principle. This modification account for finite size of electrons, preventing the formation of unphysical clusters at temperatures lower than the dissociation temperature of the hydrogen molecule [4]. The work is supported by the Russian Science Foundation (project No. 24-19-00746).

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Development of a double-ridged horn antenna in the range of 1-10 GHz

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In order to register the radio emission of a laboratory pulsed high-voltage discharge [1] , a model of a double-ridged horn antenna was created in the CST studio suite. After creating the antenna model, all its parameters were checked to ensure that it meets the requirements of the $VSWR < 2$. The verification of antenna parameters included an analysis of its radiation pattern, gain, input impedance, and other characteristics. These parameters were critical to ensure compliance with the requirements of the task. As a result of the simulations and checks, it was confirmed that the developed antenna model meets all the necessary criteria for successful registration of radio emission from laboratory pulsed high-voltage discharges. The study was supported by the Russian Science Foundation (grant No. 23-19-00524).

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Study of the dynamics of dust structure in the region of narrowing of the current channel in helium in a strong magnetic field

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To study the magnetic properties of dusty plasma it is necessary to create a magnetic field corresponding to the magnetization of the ion component of the plasma and observe its effect on the dust structure. It is very attractive to use the lightest gas helium and a strong magnetic field.

The paper studies the dynamics of rotation of a plasma-dust structure formed in a glow discharge in helium in the area of narrowing of the current channel in a magnetic field of up to 1.5 T. The cyclotron radius of a helium ion at B = 1.5 T becomes less than the screening length. The rotation velocity of the volume dust structure in the central section of the discharge inside the insert narrowing the current channel is measured depending on the induction B. The correlation of the rotation velocity with the position of the structure inside the dust trap is observed. Two regions of the magnetic field in which the rotation velocity reaches 35 rad/s are found. These regions are significantly spaced on the magnetic field scale (about 1 T). Possible rotation mechanisms are qualitatively discussed. A model is proposed that assumes two mechanisms of dust particle rotation: ion drag and neutral gas drag.

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Radial temperature distributions in a supersonic plasma jet of a pulse capillary discharge

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The construction of the radial temperature profile $T(r_x)$ is based on the following principle: at any radial coordinate r_x in axisymmetric equilibrium plasma, there is an equality between two normalized quantities: (1) the Abel-transformed relative intensity of the selected spectral line $J(r_x)/J_{\max}[T_N(r_N)]$, and (2) The equilibrium population of the line's radiating energy level $n \cdot (T)/n_{\max} \cdot (T_N)$. Both quantities are normalized to unity. We developed a program to process the experimental data and calculate the radial temperature profiles $T(r)$ taking as an example a supersonic plasma jet of a pulse polymer capillary discharge. The program accounts for the influence of the "normal" temperature T_N on the local pressure of the plasma medium (1–10 bar) on the result. Comparing the temperature profile obtained by the T_N method using the C II 426.7 nm line to the profiles obtained with the C III 418.7/C II 426.7 nm and C II 426.7/C II 407.5 nm line intensity ratio methods, we show that the former is characterized by the smallest measurement error $(\delta T/T) \leq 7\%$ and covers a larger discharge region with temperature values from 3.5–3.8 eV on axis to $T \approx 1.8$ eV at the periphery. Simultaneous and independent determination of the $n_{\mathrm{e}}(r)$ profile from the Stark component of the local contours of the C II 426.7 and C III 418.7 nm lines allows us to conclude that Saha-Boltzmann equilibrium is present in the highly ionized axial region of the plasma.

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Obtaining copper nanoparticles in glow discharge at excitation of sound waves in a gas-discharge tube

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Experimental results are presented on the obtaining of copper particles in a medium pressure glow discharge at sound wave excitation in a gas-discharge tube with two plane-parallel, cooled copper electrodes. After ignition of the discharge in argon, the sound waves were excited using a speaker attached to the tube through a confuser.
Formation of particles occurs when individual atoms, obtained due to cathodic sputtering, are recruited and arranged in an ordered structure, i.e. enlargement of initial elements (copper) to particles is achieved. The morphology of the particles was investigated using scanning electron microscopy. Sub-micron particles and nanoparticles were obtained. The formed particles have a shape close to octahedral. The formed particles acquire a crystalline structure due to local heating owing to surface plasma-chemical reactions [1, 2]. Since in the glow discharge plasma the temperatures of electrons and ions are very different ($T_e >> T_i$) [3], the tube walls and particles are negatively charged [4]. This is indirectly evidenced by the deposition of particles on the upper electrode (anode), in the opposite direction of gravity.
This work was supported by the Russian Science Foundation (Project No. 23-79-01169, https://rscf.ru/en/project/23-79-01169/).

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Simulation of accumulation of low-temperature extreme-ultraviolet-induced plasma of Ar, He and H_2

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Extreme-ultraviolet (EUV) lithography solves the task of gas protection of the chamber from contamination by a continuous flow of buffer gas [1]. Argon (Ar), helium (He), and hydrogen (H_2) have the best transmittance in this spectral range [2]. The characteristic gas pressure in the EUV photolithograph scanner is several pascal, and the temperature is 300 K [3]. The buffer gas ionization is the result of EUV radiation passing through the chamber. A series of consecutive EUV pulses causes plasma accumulation. The electrons generated in the next pulse interact with the pre-accumulated plasma. This leads to a change in the distribution of absorbed energy between the excited states of the buffer gas, the heating of electrons and the ionization of the buffer gas. In this study, we investigate the effect of plasma accumulation in the chamber on the energy distribution among the formed states following the next EUV pulse using the particles-in-cell simulation. The plasma of three different gases (Ar, He, and H_2) is compared. The pressure of the buffer gases is selected according to the same transmission coefficient. Three levels of plasma accumulation are considered: 1x is no plasma in the chamber and only neutral gas, 10x and 20x are concentration estimates obtained after 10 and 20 consecutive pulses, respectively.

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Installation for studying the interaction of electric discharge plasma with the surface of solutions

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The work presents an installation for studying the interaction of electric discharge plasma with the surface of aqueous solutions. The installation implements an original system for maintaining an adjustable liquid level in a flow discharge cell. The special case when the solution level coincides with the edge of the discharge cell is most interesting for optical studies of the discharge. It is shown that in this case it is possible to obtain photographs of the plasma interaction area with the liquid surface that are not distorted by the superposition of plasma radiation reflected from this surface. The installation can be used for a wide range of studies of the interaction of electric discharge plasma with the surface of liquids, including using optical methods and emission spectroscopy methods.

Avalanches of nanoexplosions of tungsten nanowires

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The dynamics of Joule energy release in helium-filled tungsten nanowires is considered on the basis of new conductivity estimations [Tsventoukh, Kulagin 2024 *Phys. Plasmas* 31 092509] taking into account electron scattering on an ensemble of helium nanobubbles. The minimum value of the current density was obtained, corresponding to the dominance of Joule heating over cooling by heat conduction. The minimum value was approximately 10 MA/cm^2. For a macroscopic spot, this value agrees with experimental observations and predicts the duration of explosive overheating in an ensemble of nanowires to be in the range of hundreds of nanoseconds.

It was shown that helium-filled single nanowire overheating time should be less than 10s of ps – id est faster than bubbles bursting time, which is annealing of nanowires. The corresponding current density is about 1 GA/cm^2. It provides energy release of about 10^{14} W/cm^3.

Fast (10s ps) explosion of nanowire results in massive release of helium, which flux to the neighboring nanowire can provide fast transfer of energy (comparable with value of 10^{14} W/cm^3) contributing to its explosion. Therefore, the exploding nanowires may 'interact' via large fluxes of He massively released from them, providing avalanche-like multiplication of explosions.

The hydrodynamic time for the formation of nanodroplets and exploding nanonecks from the remaining tungsten also occurs on the picosecond scale. This characteristic time is also related to the electron-phonon relaxation process, when the charge state observed experimentally is formed in an non-ideal plasma (see Tsventoukh 2021 *Phys. Plasmas* 28 024501).

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Investigation of gas flows created by a discharge with a liquid electrolyte cathode

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The discharge with a liquid electrolyte cathode at atmospheric pressure in the air was studied using PIV and high-speed photography methods. The velocity field of the gas flows created by the discharge was found. It was shown that the gas flow created by the discharge moves down along the discharge channel to the surface of the solution, reaching a maximum velocity near its surface. Meeting with the surface of the solution, the gas begins to spread along it in a thin layer about two millimeters thick. Thus, it was found that the components of the solution transferred from the solution to the gas phase under the action of a discharge with a liquid cathode are removed from the discharge zone in a horizontal direction, along the surface of the solution.

The use of gas discharge Penning ion sources in inertial electrostatic confinement systems

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The report presents the results of studies of the performance characteristics of gas-discharge Penning ion sources (IS) when they are used to inject ions into inertial electrostatic confinement (IEC) systems. The work carried out earlier by various authors has shown the expediency of using discrete IS in IEC systems, for example [1, 2]. IEC systems of linear, cylindrical or spherical geometries are also used for various operating conditions [3]. In this report, the use of Penning IS in case of linear and spherical geometry of a neutron emitting IEC system based on nuclear fusion reactions of hydrogen isotopes is considered. The current characteristics, power modes of the submilliampere and milliampere IS are considered, and the operation of neutron emitters based on them is compared.

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Doppler and pyrometric diagnostics of shock-compressed plasma of dense xenon

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Various gases are used as reference materials in the experimental determination of the state parameters on the isentropes of explosion products by the barrier method in the pressure range below 5 Gpa. The most widespread noble gases are argon, xenon, and krypton. Due to the development of computational modeling methods and tools, there has recently been a need to clarify the equation of state of explosive explosion products and, accordingly, reference materials. The introduction of Doppler diagnostic methods (microwave interferometer and PDV heterodyne interferometer) suggests that this problem can be solved if the areas of their applicability in studies of shock wave compression of gases are determined.

Experimental studies of the shock wave compressibility of xenon, initially located at a pressure of P_0=5 atm, in the range of mass velocities from 1.7 to 8.1 km/s using a heterodyne interferometer, radio interferometer and pyrometer, have been carried out. The fundamental possibility of detecting a shock wave in xenon using a PDV heterodyne interferometer above 2 km/s is demonstrated. The experimental data obtained on the shock wave compressibility of xenon are in agreement with the experimental results of other researchers and with the calculation results based on the chemical plasma model.

According to the results of measurements of the brightness temperatures of shock-compressed xenon, using an optical pyrometer, a manifestation of the shielding effect of uncompressed ionized xenon was detected.

The influence of electric discharge on two-phase water-oil system interface

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In this work, electrohydrodynamic flows and the formation of electrical breakdown across the interface between water and transformer oil in a pulsed electric field are studied experimentally and using mathematical modeling. In the investigated voltage range, which is obviously lower than the oil breakdown voltage, breakdown occurs through the growth of a water cone through the oil to the high-voltage electrode and the closure of the gap. Depending on the electrical conductivity and amplitude of the applied voltage, after the cone reaches the high-voltage electrode, current may flow without plasma formation, a plasma region may appear after touching, or a plasma region may appear before touching the cone due to breakdown through individual droplets sprayed from the top of the cone. The two-dimensional modeling performed showed good agreement with the experiment of the shape of the resulting cone. The time lag of approximately 1.4 times from the experiment is probably due to the two-dimensional formulation of the problem, in which a portion of the field strength associated with the extension of the high-voltage sphere along the third direction in the model is lost. Taking into account the electrical conductivity of water can also speed up the process due to greater displacement of the field from water and its strengthening at the interface. Thus, it seems appropriate to carry out further calculations in a three-dimensional formulation and experimental estimates of the effective thickness of the interface taking into account capillary waves to refine the model formulation.

Selection of optimal conditions for deposition of thin IGZO films by PECVD method

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Indium gallium zinc oxide (IGZO) is one of the most promising semiconductor materials as an active layer in Thin Film Transistors (TFT). Thin IGZO films have advantages such as good stability, transparency in the visible range, and high charge carrier mobility [1].
Thin films of indium gallium zinc oxide (IGZO) were obtained by plasma-enhanced chemical vapor deposition (PECVD) [2]. Optimal deposition conditions for these thin films were selected. During the experiments to obtain films of better quality, the following synthesis conditions were varied: the ratio of the starting metals in the alloy and their evaporation temperature, the flow rate of the carrier gas, and the plasma discharge power. The obtained layers have a homogeneous surface structure and a uniform distribution of elements across its area, indicating the applicability of this method for obtaining IGZO thin films. Based on the results of a series of experiments, optimal deposition parameters for IGZO thin films by the PECVD method were determined: 1) Precursors: metallic zinc, indium-gallium alloy (60 at.2) Zn temperature 290 °C, In-Ga temperature 800 °C; 3) Carrier gas flow rate - 4.5 ml/min (0.01 Torr); 4) Plasma discharge power 50 W.

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The thermophysical properties of low-temperature tin plasma

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The thermophysical properties (thermodynamics and the electronic transport coefficients) are significant in various areas of area physics, including the region of the low-temperature plasma (LTP) of metals. The latter is located approximately at the temperatures 10 kK$\leq T \leq$ 100 kK and the densities $\rho \leq \rho_c$, where ρ_c is the critical densities. Presently, there are many investigations both in the calculations and in the experiments of the considered properties in LTP for various substances, including metals [1]. However, the data for many metals in LTP are still divergent even within the most exact *ab initio* simulations [1]. Moreover, there are some metals, including tin, for which corresponding data are absent in LTP. Tin has low melting temperature T_m= 505.08 K. Thus, its thermophysical properties in liquid state had been already measured with good accuracy 50 years ago [2]. The same concerns the high pressure phase diagram (but at T $\leq$ 3 kK) [3]. But at temperature increase there much less data. In particular there are the shock wave measurements data near the normal density (ρ_0=2.829 g/cm^3) [4]. However, in LTP there are no appropriate data, excluding for only semi-empirical models [5, 6]. So it is necessarily to fill this gap.Previously we have developed a model to calculate the properties under study for different metals in LTP state. It was successfully applied to various substances, see [7] and references therein. Now we have applied it to tin.

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Control of microparticle oscillations by the thermal field in a plasma of a glow discharge

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Thermal fields can be applied for change the shape and separate into parts the structures of microparticle. In the present work, we research the dynamics of polydisperse charged microparticles in plasma of a DC discharge upon changes in the radial thermal-field gradient. It is demonstrated that the thermal field can be used for effective control of a cloud of microparticles formed in an electrostatic trap of stratum the positive-column stratum of discharge. The discharge was ignited in air with polydisperse (3—10 micron) particles in a vertical tube with the inner diameter of 5 cm. The air pressure varied in the range of 0.1—0.5 Torr, while the discharge current varied in the range of 0.25—1 mA. Radial temperature gradient in plasma was varied by changing the tube wall temperature. The required wall temperature was achieved by means of two chillers mounted coaxially on the wall opposite to the cloud of microparticles. Variation in the tube wall temperature is found to cause changes in the cloud location in plasma volume, its shape and size, along with suppression of oscillations of microparticles in the directions transverse with respect to this gradient. Microparticles of larger size experience stronger thermal action. Changes in location of the cloud of microparticles were accompanied by redistribution of the stratum glow intensity caused by considerable plasma losses upon interaction with microparticles and additional ionization. Damping of oscillations of microparticles with increase in the thermal-field gradient was discovered, and its efficiency was estimated. By analogy with free damped oscillations, the obtained damping of large microparticle oscillations would be characterized by a very large damping decrement of 3.

Generating of a toroidal plasma vortex in the atmosphere by electrical exploding of copper wires using a water seal

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Generating of a toroidal plasma vortex in the atmosphere was carried out using a pulse plasmatron containing a vertically located semi-open cylindrical chamber with a diameter of 90 mm and a height of 60 mm. Electrodes were located at the bottom of the chamber and on its side surface, to which 32 electrically exploded copper wires were attached. The wires were installed so that they could create a toroidal magnetic field with an amplitude value of magnetic induction of about 2 T. Water was poured onto the bottom of the chamber so that the ends of the electrically exploded wires were covered with a layer of water about 5 mm thick. The electrodes were connected via a thyristor switch to a 1 F capacitor bank charged to 400 V. During the experiments, an electrical exploding copper wires was carried out, with the peak current reaching about 400 kA. In this case, due to the water seal, a shortened trailing edge of the current pulse was provided, amounting to about 50 microseconds. This contributed to the additional introduction of energy into the plasma vortex due to the induction discharge under the action of the trailing edge of the rapidly decaying toroidal magnetic field. As a result, a toroidal plasma vortex with increased luminosity with a lifetime of about 100 ms was generated.

Impact of barrier discharge on water spray formation

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The direction of plasma physics associated with the so-called plasma activation of water has been actively developing [1]. When an electric discharge is ignited near the surface of water, active chemical components are produced and dissolved in the volume of liquid [2]. The following chemicals are of interest: ozone, hydrogen peroxide, nitrogen oxides [3]. When these active compounds are added to water, it can be disinfected, decolorized, and purified from certain types of pollutants [2]. Since active compounds usually decompose quickly, the efficiency depends on the surface area of the water with which plasma comes into contact. It seems more efficient to create an electric discharge in dispersed water: in bubble water or in an aerosol [2]. The results of measuring the properties of water spray obtained using a swirl nozzle in the presence of an electric field and barrier discharge plasma in the air are presented. The parameters of water spray droplets were measured using the direct shadow method. Spatial distributions of averaged spray parameters (average diameter, Sauter mean diameter) were experimentally obtained in cases with and without discharge. The distributions were integrated to determine the spatially averaged parameters. The data obtained indicate that the effect of the electric field consists not only in changing the trajectory of droplets, but also in accelerated disintegration of the liquid film near the nozzle outlet.

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