XXIth Winter School on Continuous Media Mechanics

Plenary lectures

Professor

Aronson Igor S.

Pennsylvania State University, USA

Swimming in a superfluid

The propulsion of living microorganisms ultimately relies on viscous drag for body-fluid interaction. The self-locomotion in a superfluid such as ^{4}He deems impossible due to apparent lack of the viscous resistance. We investigate the self-propulsion of a Janus (two-face) light-absorbing particle suspended in superfluid helium ^{4}He (often called He-II). The particle is energized by the heat flux due to the absorption of light from an external source. We show that a quantum mechanical propulsion force originates due to the transformation of the superfluid to normal fluid on the heated particle face. The theoretical analysis is supported by the numerical solution of the Ginzburg-Landau-Khalatnikov model for a superfluid. Our results shed light on the dynamics of inclusions in a superfluid and stimulate new experiments.

Professor

Akhatov Iskander Shaukatovich

Center for Design, Production Technologies and Materials, Skolkovo Institute of Science and Technology (Moscow)

Hydrodynamics of Dispersed Systems: Fundamentals and Applications

The dynamics of dispersed systems is a branch of mechanics that studies aerosols (liquid drops dispersed in a gas), emulsions (liquid drops dispersed in another liquid), suspensions (solid particles dispersed in a gas or liquid), powders (packed porous media) and bubble fluids (bubbles dispersed in a liquid). Because of its practical relevance, the dynamics of dispersed systems has been the focus of multi-year studies by many research groups around the world and has been successfully used in Russia and abroad to solve problems of nuclear, petroleum, chemical, and environmental engineering.

This paper discusses applied fundamental problems in hydrodynamics of dispersed systems relevant to industrial applications. Namely: (1) convective combustion and detonation in powder explosives; (2) collapsing bubbles and sonoluminescence; (3) acoustic cavitation and bubble clouds; (4) collimation of aerosol beams; (5) capillary deposition; and many others.

Professor

Baggioli Matteo

Institute of Theoretical Physics University of Madrid

(Madrid Spain)

Find the differences between solids and liquids (and understand them)

The vibrational, thermodynamical and mechanical properties of solids are well-understood since Debye's work in 1912. On the contrary, the same understanding for amorphous systems, liquids and glasses, has remain elusive for more than a century and it is still a mystery. In this lecture, I will propose a new distinction between solids and liquids based on non-affine displacements and a topological higher form symmetry which can be quantified by using the concept of Burgers vector applied to the dynamical displacement fields.

The breaking of such a symmetry results in a macroscopic phase relaxation rate for the Goldstone modes, which consequently acquire a finite propagation length. I will show how this theory reproduces perfectly the k-gap dynamics for shear waves and the positive sound dispersion phenomenon for longitudinal sound in liquids.

Corresponding Member of the Russian Academy of Sciences

Vasilevsky Yury Victorovich

G.I. Marchuk Institute for Computational Mathematics of the Russian Academy of Sciences, MIPT, Sechenov University (Moscow)

V.V. Vasilevsky, K.D. Nikitin, R.M. Yanbarisov, K.M. Terekhov, M.A. Olshansky

Three-dimensional flows of Newtonian and non-Newtonian fluids with a free surface

This lecture is concerned with modeling of three-dimensional flows of Newtonian and non-Newtonian fluids with a free surface.

The fundamental principle of modeling is to make minimal assumptions about fluid and flow features, so that the model is based on the Navier-Stokes equations and the equation of layer function transfer to trace the evolution of the free surface.

The high resolution of the free surface is provided by using dynamic octree-based adaptive grids.

Numerical examples illustrate solutions to different problems ranging from elliptical droplet oscillations to computation of the action of hurricane-induced loads on offshore structures and mudflow descent models.

Professor

Vatulyan Alexander Ovanesovich

Southern Federal University (Rostov-on-Don)

Determination of Variable Physical Characteristics of Elastic Bodies

A number of inverse problems in mechanics of deformable solids are considered to identify several variable characteristics such as moduli of elasticity and density using amplitude-frequency characteristics measured at the boundary of the body. General principles of investigation of nonlinear ill-posed problems arising during a search for solutions are formulated. A formulation of the operator relations of inverse problems is proposed and the appropriate iterative processes are constructed. At each step of the iterative process the direct problem with known characteristics is solved and corrections are found by solving the operator equations and the systems with compact operators. The sensitivity of input information to the desired functions is examined. Problems of longitudinally inhomogeneous bars and radially inhomogeneous cylindrical structures (circular cylinders and waveguides) are considered as the examples of reconstruction. The results of computational experiments are presented and some principles of loading, providing the most effective reconstruction, are formulated.

Professor

Georgievsky Dmitriy Vladimirovich

Lomonosov Moscow State University (Moscow)

Elements of the Theory of Constitutive Relations and Linearized Formulations of Stability Problems

Elements of the Theory of Determinative Relationships. Tangent modulus and tangential mobility. Physical linearity, tensor linearity (quasi-linearity) and non-linearity. Material functions. Rayon and scleronome media. Homogeneous and inhomogeneous media. Composites. Elastic bodies. Viscous fluids. Mediums with memory. Non-local media.

Tensor functions and their invariants in the theory of defining relations. Potential media and potentiality conditions. Incompressible materials.

Nonlinear elastic-viscoplastic models. Classification of incompressible media (quasi-linear models, Bingham bodies, ideal plastic media, Newtonian viscous fluids).

Statement of linearized boundary value problem of flow stability with respect to small perturbations of initial data.

Professor

Giuliani Alessandro

Istituto Superiore di Sanità (Italian NIH) (Roma, Italy)

Force matters: some notes on mechano-biology

The investigation of the effect of mechanical forces on living matter is shaking the bases of biological thought. At odds with a long standing tradition positing the ultimate causal origin of any manifestation of living at the genetic level, there is increasing evidence gene expression can be intended as a response to microenvironment changes. Mechanical forces have a predominant role in cell microenvironment. Here I will discuss some examples going from microgravity effects to chromosome structure and resonance phenomena.

Professor

Еремеев Виктор Анатольевич

Gdańsk University of Technology (Gdańsk, Poland)
University of Cagliari (Cagliari, Italy)

On antiplane surface waves within strongly anisotropic surface elasticity

The aim of the lecture is to discuss a new model of surface elasticity called strongly anisotropic. The model was motivated by consideration of certain inhomogeneous microstructured coatings. The motivation of these surface structures is at least twofold. The first relates to polymeric brushes. The interest to modelling of coatings made polymeric brushes relates to recent developments in superhydrophobic and superoleophobic surfaces used for manufacturing of so-called self-cleaning and bactericide coatings. Another example of such coating is hyperbolic metasurfaces.

First we briefly recall discuss the structure of a coating. Then we present a continuum model with surface energy density. From the physical point of view this model corresponds to a coating made of a family of parallel long fibres possessing bending and extensional stiffness in one preferred direction. Finally, using the variational Lagrange principle we derive the equilibrium equations and the corresponding natural boundary conditions. The presented 2D model can be treated as a highly anisotropic 2D strain gradient elasticity. The surface strain energy contains both first and second derivatives of the surface field of displacements. So it represents a class of 2D models of the surface elasticity which is intermediate between the Gurtin-Murdoch and Steigmann-Ogden ones. Finally, we discuss the propagation of antiplane surface waves.

Professor

Kukushkin Sergey Arsenievich

Institute for Problems of Mechanical Engineering of Russian Academy of Sciences (St. Petersburg)

S.A. Kukushkin, A.V. Osipov

Micromechanics of heterostructures and controlled synthesis of new materials: Nanoscale monocrystalline silicon carbide- on- silicon and its unique properties

Using the fundamental principles of deformable solid mechanics, we theoretically elaborated and experimentally implemented a principally new method of controlled synthesis of single-crystal, low-defect semiconductor films with prescribed properties and structures on substrates with a considerable mismatch between the lattice parameters of the film and the substrate. On the basis of this method the technology of obtaining a new material - monocrystalline silicon carbide -on- silicon nanofilm was developed. The method is based on the newly discovered mechanism of relaxation of elastic mechanical stresses during the growth of epitaxial films by preliminary introducing into the substrate lattice an ensemble of nanoobjects-dilatation dipoles, which are stable complexes consisting of attractive dilatation centers - a carbon atom in the interstitial position of silicon and a silicon vacancy. For the first time in the world practice we implemented the method of consecutive replacement of atoms of one kind by another directly inside the original crystal without destroying its crystaline structure. The method resembles the "genetic synthesis" of protein structures in biology. The quality of the layer structure obtained by this method is significantly higher than the quality of silicon carbide films grown on silicon substrates -the technology used by the world's leading companies. The method is cheap and easily producible. The technology has now passed the R&D stage. For the first time a working laboratory prototype (light-emitting) of LED structure on silicon with a silicon nanocarbide sublayer was created. Work is currently underway to launch in Russia the production of silicon-based LEDs. Considerable efforts are focused on the development of thin-film transistors with high mobility of charge carrier (HEMT), pyroelectric sensors, and night vision sensors, which operate steadily over a wide temperature range. Works on creating highly sensitive piezosensors and acoustic membranes are in progress.

The formation of a new Si phase located in the "half-metal" state at the SiC(111)/Si(111) interface has been theoretically predicted and experimentally confirmed. The formation of Si in the "half-metal" state at the SiC/Si (111) interface is associated with large, short-lived (pulse time of the order of 10^{-5}-10^{-4} sec.) "squeezing pulses" during Si to SiC transition. It is shown that the compression pressures occurring in a thin boundary layer with a thickness of the order of several nanometers can reach values of the order of 200-250 GPa. Pressures of this magnitude lead to the formation of special, previously unknown, properties of the SiC(111)/Si(111) interface.

This work was carried out within the framework of the Russian Science Foundation Project No. 20-12-00193.

Professor

Lurie Sergei A.

Ishlinsky Institute for Problems in Mechanics named after A.Yu. RAS (Moscow)

V.V. Vasiliev, S.A. Lurie

Investigation of the strength of cracked plates in terms of stress concentration determined in the nonlocal theory of elasticity

In recent years, the problem of singularities has been widely discussed in the context of the theory of elasticity and crack mechanics. The singularity of solutions for stresses in the linear theory of elasticity excludes the use of traditional criteria for the strength of bodies with stress concentration. Alternative approaches, developed using models of cohesive zones, the theory of size effects, the peridynamic theory of elasticity, the theory of critical crack openings, etc., have attracted much attention in the last few decades.

Gradient elasticity and the nonlocal theory used in this work (close to the peridynamic theory) provides regularization of singular solutions of differential equations of elasticity theory, makes it possible to describe dimensional effects and allows the use of traditional methods of strength assessment. This study is concerned with the version of the generalized theory of elasticity, constructed using the technique of nonlocal differentiation, where the solution of the boundary value problem is split, under static boundary conditions, into a sequence of solutions of classical elasticity and the boundary value problem for the Helmholtz equation. In the general case, it is suggested that nonsingular solutions for the stress tensor can be constructed by solving the inhomogeneous generalized Helmholtz equations for the generalized stress function. This yields a solution to the problem of consistency of generalized stress components, and the fracture criterion is formulated in terms of local Cauchy stresses. Isotropic and orthotropic materials are considered.

The concept of stress concentration for fracture mechanics proposed in this study enables predicting both the ultimate stresses for brittle cracks and the onset of the yield strength for non-brittle materials. Our approach involves experimental determination of the scale parameter of the medium model, entering the equations of the generalized theory, and calculation of the stress concentration factor at the crack tip.

An attempt is made to process the experimental results obtained for the materials with cracks using the concept of stress concentration and the finite element method implemented for the gradient theory of elasticity. Consideration is given to failure criteria for stresses, which have finite values over the entire region, including the crack tip. In other words, the standard method for assessing strength from the stress concentration used in the classical theory of elasticity for bodies with regular geometry is applied to the bodies with cracks, taking into account the deformation gradient effects. (This study was supported by RFBR Grant 19-01-00355).

Professor

Mizonov Vadim E.

Ivanovo Power Engineering University (Ivanovo)

Application of the theory of Markov chains to modeling physicochemical processes in continuous and dispersed media

The strategy of applying the theory of Markov chains to mathematical modeling of transport processes in continuous and dispersed media is described. The theory makes it possible to model transfer processes and can be applied to study the evolution of distribution of state probabilities in some selected space of states. Modeling of transfer processes indicates how a certain property is distributed in a chosen space of states of this property. The space where the property changes is divided into a finite number of small cells of ideal mixing with a uniform distribution of this property within each cell. This distribution is described by a state vector, and its evolution - by a transition matrix (matrix of transition probabilities), which is a mathematical image of the process or apparatus under study and is constructed according to standard rules. The undoubted advantage of this strategy is that very heterogeneous processes can be modeled on the basis of a universal algorithm available in engineering practice. The efficiency of the theory for modelling specific processes is confirmed by the following factors: formation of multicomponent mixtures of dissimilar dispersed materials, nonlinear thermal conductivity in a multilayer medium with phase transitions in layers, and nonlinear thermal conductivity in a medium with a moving boundary (Stefan's problem).

Professor

Mileiko Sergey T.

Institute of Solid State Physics RAS, (Chernogolovka, Moscow region)

Metal matrix composites: state of the art, unsolved problems, prospects

Modern composites science owes its appearance to composites with a metal matrix (MMC), which in the mid-60s of the last century were used by A. Kelly as model materials. However, these materials were seemingly developed ahead of the time, and therefore were withdrawn into the shadows due to the aggressively beneficial spread of carbon fiber reinforced plastics (CFRP). The advent of these plastics was firstly caused by the understanding of the necessity for replacing metal alloys (MA), which reached their limiting potential for use in the key industrial branches (aircraft industry, nuclear industry, etc.), by novel materials with fundamentally new properties and capabilities and proved capable of providing technology leaps. This understanding arose in the scientific, engineering and government circles of Russia during the Soviet period of its history and in the countries on the other side of the Iron Curtain, first, due to the works of Kelly and his contemporaries and then due to the occurrence of new carbon fiber manufacturing technology.

Advances in the development of ceramic matrix composites have also contributed to this “vegetation” of MMCs in the shade. These materials were used only occasionally, in particular, boron-aluminum demonstrated its unique capabilities, for example, when launching the first satellites of the GLONASS system. At the same time, they demonstrated weaknesses associated mainly with the high cost of the corresponding reinforcing fibers.

Today's "relationship" in the MMC-CP pair reminds of the situation in the CP-MA pair, which took place half a century ago: CFRPs are approaching, in terms of their development, metal alloys and the next qualitative leap in the characteristics of vital areas of technology is impossible without a leap in the characteristics of structural materials. These should be fiber composites with a metal matrix.

Using carbon fiber-titanium matrix and oxide fiber-molybdenum matrix composites developed in the author's research group as an example, I will discuss (1) some unsolved problems of the technological mechanics of composites, (2) the prospects for the development of new MMC, (3) technological, economic and environmental effects associated with the application of MMC structures in aviation and rocket and space technology.

Professor

Noskov Boris A.

Saint Petersburg State University (Saint Petersburg)

The surface of a liquid in the twenty-first century

The mechanics of a free surface liquid must inevitably take surface properties into account. Until the middle of the last century, the only characteristic of a liquid, which was considered in the framework of hydrodynamic problems, was surface (interfacial) tension. The second half of the twentieth century was marked by the development of the problems, in which surface rheological properties must also be taken into account. A classic example is the problem of attenuation of surface waves. Calculation of the damping coefficient without taking into account the dilatational surface elasticity leads to values that are several times smaller than the experimentally determined value. In the physical chemistry of surface phenomena, the use of dilated surface rheology has made it possible to obtain new information about the processes in the surface layer of surfactant solutions. The twenty-first century is characterized by the expansion of the arsenal of experimental methods for the chemistry of surface phenomena and, at the same time, by the application of these methods to more complex systems containing macromolecules and nanoparticles. Nano- and microparticles can be adsorbed from the bulk phase, but they can also spontaneously form at the interface, leading to new effects affecting the fluid flow. On the other hand, the interpretation of experimental results, in particular, in terms of effective surface tension and surface rheology turns out to be more difficult.

It is planned to present a brief review of recent results illustrating the properties of adsorption and deposited surface nano- and microheterogeneous films at the liquid-gas interface.

The work was supported by RFBR (project N 18-29-19100 mk).

Professor

Plourabouè Franck

Институт механики жидкостей Тулузы, (г.Тулуза, Франция)

Recent developments on Ionic wind analysis

Ionic wind is of interest in several applications such as electrostatic precipitors, gas pumps, particle analyzers, miniaturized heat coolers, electro-photography and more recently Aero-Electro-Dynamic (AED) propulsion. During this presentation a short survey of recent advances in the field will be first presented, especially Focusing on propulsive applications.

From a more fundamental viewpoint, the presentation will also discuss the physics of corona discharge, and its modeling.

Some new modeling results will then be presented associated with two distinct approaches. On the one hand, the use of Kaptzov approximation at emitters permits a modeling of the drift-region using a self-adapted mesh-refinement strategy within a finite-element solver permitting the exploration of many emitters/collectors configurations. This approach albeit approximated, already provide interesting predictions for the main quantities of interest, i. e, the predicted current and the propulsion force. On the other hand, a new approach, based upon a multi-polar expansion of the photo-ionization kernel, permits to split the corona discharge/drift region modelling issue into two local (non-linear) coupled problems. Some example of coupled solutions and their comparison with Kaptzov approximation at emitters will be provided. Perspective for the domains will be discussed at the end of the presentation.

Professor

Proud William

Shock Wave Institute, Imperial College, (London, UK)

W.G. Proud, G. Tear, D. Sory, S. Rankin and K. Brown

The Dynamic Response of Non-linear materials: Damage in Biological and Engineering materials

This presentation will consider the measurement of damage to three types of material, the damage process and the consequences of each. The materials come from different sources and are heterogeneous in nature. Cement where microwave-induced microcracks have a marked effect on the dynamic strength. Polymers where a combination of strain-rate, temperature and structure produce a complex strength and damage response and, finally, the loading of human STEM cells where pressure, strain-rate and environment have a marked influence. In each case the emphasis will be on the need to consider the type of measurement required, adaption of loading systems and how measurements can be used to characterise non-liner materials.

Professor

Sevostianov Igor B.

Mechanical engineering, New Mexico State University,
(New Mexico, USA)

Effective properties of heterogeneous materials in relation to their microstructures and cross-property connections

The presentation focuses on the proper quantitative characterization of microstructures of heterogeneous materials in the context of modeling their effective properties. This is a broad subject that covers different physical properties (elastic, thermal, electric, etc.), as well as various types of microstructures. Proper microstructural parameters must correctly represent the individual inhomogeneity contribution to the considered property. They may differ for different physical properties. The key problem is to identify the mentioned individual contributions. The possibility of explicit cross-property connections, which relate *changes* in different physical properties caused by various inhomogeneities (cracks, pores, inclusions), depends on the possibility to express the two properties in terms of the same or similar microstructural parameters. Practical usefulness of the cross-property connections lies in the fact that one physical property (say, electrical conductivity) may be easier to measure than the other (say anisotropic elastic constants). This allows one to bypass difficulties of expressing the elastic properties in terms of relevant microstructural information (that, in addition, may not be available). Such connections are also helpful in the design of microstructures for the *combined* conductive/mechanical performance and in monitoring of accumulated damage. We also discuss the possibilities of cross-property connections involving strength and plasticity parameters. Theoretical results are illustrated by multiple applications recently developed in the Center of Micromechanics at New Mexico State University

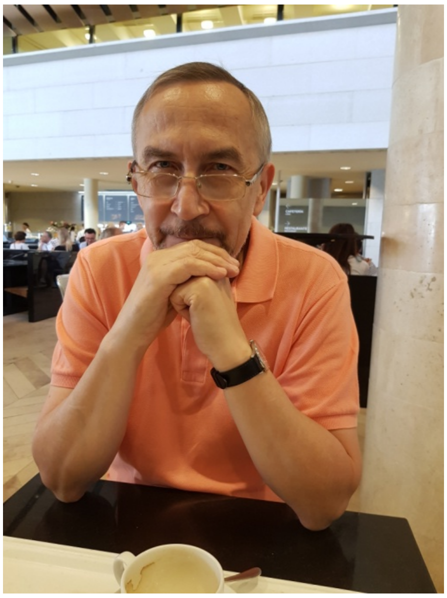
Full member of RAS, Professor

Tuchin Valeriy V.

Saratov National Research State University named after N.G. Chernyshevsky (Saratov);
Precision Mechanics and Control of the Russian Academy of Sciences (Saratov);
Interdisciplinary Laboratory of Biophotonics, National Research Tomsk State University (Tomsk);
FemtoMedicine Laboratory, ITMO University (St. Petersburg);
Federal Scientific Center for Biotechnology RAS (Moscow)

Optical Clearing of Biological Tissues: Towards Multimodal Medical Diagnostics

The lecture will briefly describe the optics of biological tissues, the concept of "transparency windows of biological tissues" and the method of optical clearing (OC), based on a controlled and reversible modification of the structural and optical properties of tissue by it immersion into biocompatible optical clearing agents (OCA). Consideration will be given to the fundamentals and mechanisms of OC, allowing one to significantly improve the quality of optical imaging and the efficiency of laser action on living objects. The transfer of water in tissues and changes in their properties under the influence of OCA, including reversible dehydration and shrinkage, the balance of free and bound water, will be analyzed. Increasing depth of probing (or exposure) and contrast of optical, CT and MRI images for various tissues of humans and animals, including skin, sclera of the eye, dura mater, brain tissue, myocardium, muscle tissue, cartilage and bone tissue, blood and other tissues, will be demonstrated through an analysis of the results obtained using spectrophotometry, OCT, photoacoustic microscopy, linear and nonlinear fluorescence, SHG and Raman microscopy, and dynamic full-field speckle imaging. Experimental data on diffusion and permeability coefficients of glucose, glycerol, PEG, Omnipaque, Gadovist, albumin and other OCA for normal and pathological tissues will be presented. Prospects of using immersion OC / contrasting to improve visualization of living objects using various imaging methods operating in an ultra-wide wavelength range from excitation by the beams of free electrons (Cherenkov radiation) to terahertz waves will be discussed.



Professor

Chupakhin Alexander P.

Institute of Hydrodynamics named after M.A. Lavrent'ev, SB RAS (Novosibirsk)

Geometry and energetics of models of hemodynamics and brain growth

The presentation will present geometric and energetic approaches to the study of hemodynamics of cerebral vessels and the growth of the human fetal brain. Analysis of the hemodynamics of cerebral vessels is based on the data obtained during the blood flow intravascular monitoring procedure, developed in cooperation with the physicians of the E.N. Meshalkin National Medical Research Center. A significant result of this monitoring is the development and use of “pressure-velocity” (p-v) diagrams characterizing the relaxation oscillations of the hydroelastic system “blood flow-elastic vessel wall” both in normal conditions and in the presence of anomalies. For designing this hydroelastic system, a computer complex has been developed. The calculation results for the system representing a vessel with an aneurysm and a diverticulum (small subaneurysm) coincide well with the real (p-v) data of neurosurgical monitoring. The role of various energy characteristics of the system is shown: kinetic energy, viscous energy dissipation, bending energy.

Clinical data of magnetic resonance imaging of the human fetal brain, obtained at the Tomographic Center of the SB RAS, will be described. It is planned to present the basic patterns of normal fetal brain growth: a linear growth law, division of brain structures into three groups according to the values of growth rates, a high degree of correlation of growth rates for pairs of structures in the second trimester of development, and a large individualization in the third.

The issues regarding the relationship between the geometry of fetal brain structures, such as the corpus callosum and cerebellum, and the isoperimetric ratio (cube of area to square of volume) and Willmore-Helfrich energy will be discussed.