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ABSTRACT

329 | ACCELERATOR PHYSICS / HIGH ENERGY & PARTICLE PHYSICS (HEP)

330 | ACCELERATOR PHYSICS (AC) / NUCLEAR PHYSICS (NP) / PLASMA PHYSICS (PL)

THE DEVELOPMENT OF PHYSICS EDUCATION RESEARCH IN FUDAN UNIVERSITY

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ABSTRACT

Physics education research is a discipline-based education research to explore practical problems in physics education, seek effective solutions, and improve the quality of physics education and teaching. The accumulated research results have had a profound impact on the construction of physics courses and teaching reforms. This presentation will present several typical examples to briefly introduce some of the research achievements in this field by Fudan University and its collaborating institutions in recent years. It also puts forward thoughts and suggestions for improving the current situation of physics education research in China, aiming to provide reference for promoting the development of domestic physics education research.

KEYWORDS

Physics education research, Research methods, Curriculum, Instructional resources

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DIGITAL INTELLIGENCE DRIVING CLASSROOM REVOLUTION IN PHYSICS EDUCATION — A CASE STUDY OF THE BLENDED "SEMICONDUCTOR PHYSICS" COURSE

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ABSTRACT

In the era of digital intelligence, higher education is undergoing a profound shift from "teaching-centered" to "learning-centered" paradigms. Taking Fudan University's "Semiconductor Physics" course as an example , this report elaborates on how digital and intelligent technologies can be leveraged to establish a new teaching model. The course adopts a blended teaching model. In the online phase, we carry out problem-oriented learning, mind map construction, and online testing, to supplement students' knowledge gaps. Meanwhile, offline classrooms are transformed into student-led seminars, focusing on representative reports, critical discussions, in-class tests, and peer evaluations. The course assessment emphasizes process-oriented evaluation. Practice has shown that this hybrid design effectively enhances students' self-learning ability, higher-order thinking, and physics professional competence.

KEYWORDS

Digital Intelligence Driving, Physics Education, Blended Course, Semiconductor Physics

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Opportunity or Challenge? Exploring Strategies for the Symbiotic Integration of GAI and Science Education

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ABSTRACT

The rise of Generative Artificial Intelligence (GAI) presents both opportunities and challenges for a paradigm shift in science education. This study systematically examines the dual effects of integrating GAI, analyzes its enabling pathways and value-added potential, and critically evaluates the technical, ethical, and practical constraints. The study finds that GAI drives innovation through three pathways: in experimental design, by generating simulated environments that reduce cost risks and expand the boundaries of inquiry; in personalized instruction, by constructing adaptive learning pathways based on learning analytics to achieve data-driven differentiated instruction; and in promoting deep learning, by creating complex open-ended problem scenarios that guide students toward critical thinking and inquiry-based learning. This enhances the value of science education, facilitating interdisciplinary integration, personalized practice, and empowerment throughout the entire inquiry process.

However, the demands of science education for accuracy, rigor, and verifiability conflict with the limitations of GAI, such as “hallucinations,” uncertainty, and insufficient interpretability. Based on the current landscape, the study identifies practical challenges: insufficient technological applicability, particularly in high-precision scientific contexts; high implementation costs for teachers, including cognitive load, time investment, and lack of support; and data security and ethical issues involving privacy, algorithmic bias, and accountability. Therefore, there is an urgent need to develop a collaborative framework: establishing science-oriented quality standards and evaluation systems for GAI content; developing teacher professional development models centered on “human-machine collaboration” to strengthen digital literacy and technology integration capabilities; and formulating ethical governance and application guidelines to ensure technological reliability, fairness, and educational value. Through multidimensional advancement, we aim to build a new ecosystem for science education that is intelligent, trustworthy, and learner-centered.

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KEYWORDS

Generative Artificial Intelligence; Science Education; Personalized Learning; Human-Machine Collaboration; Educational Ecosystem

Emergent phenomena in geometrically frustrated quantum materials

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ABSTRACT

When several degrees of freedom in quantum materials have similar energy scales, the intertwined electronic orders, which exhibit broken symmetries, are often strongly coupled. Recent studies on kagome superconductors, such as CsV_3Sb_5, report rotational and time-reversal symmetry breaking linked to a charge density wave. Here we observe a momentum-selective response of the electronic structure of CsV_3Sb_5 to an external magnetic field. By performing angle-resolved photoemission spectroscopy in a tunable magnetic field, we demonstrate that the response of the electronic structure is compatible with piezomagnetism along with strong orbital selectivity. Our results show that the origin of the time-reversal symmetry breaking is associated with the vanadium Van Hove singularities at the onset of the charge-density-wave order. We also demonstrate the presence of fluctuations beyond the charge ordering temperature. Our results reveal that magnetic fields can be used as tuning knobs for disentangling intertwined orders in the momentum space for quantum materials.

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KEYWORDS

Geometrically frustrated lattice, strongly correlated electron systems, angle-resolved photoemission spectroscopy

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Universal laws of thermalization in lattice systems

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ABSTRACT
Over the past decade, significant progress has been made regarding the Fermi–Pasta–Ulam–Tsingou problem: whether weakly nonlinear lattices thermalize and how. Current understanding is as follows. (a) Classical lattices fall into two universal classes. In the first, the Hamiltonian has extended normal modes. For sufficiently large systems, the thermalization time scales as $T_{\mathrm{eq}} \sim g^{-2}$, where g measures nonlinearity. Thus, in the thermodynamic limit, thermalization is inevitable. Examples include common one-, two-, and three-dimensional lattices. In the second class, all normal modes are localized. Here, although $T_{\mathrm{eq}} \sim g^{-\gamma}$, the exponent γ diverges as $g \to 0$; thus, arbitrarily weak nonlinearity cannot induce thermalization, making such systems theoretical thermal insulators. (b) For the first class, disorder does not hinder thermalization. By breaking translational symmetry, disorder relaxes wave-vector resonance constraints and increases quasi-resonant processes, thereby accelerating thermalization. (c) In systems of the second class, when both on-site potentials and disorder are present, all normal modes become localized in large systems, suppressing thermalization. The perturbative framework underlying these conclusions is also outlined, emphasizing the thermalization criterion based on resonance network connectivity, an approach originating from weak wave turbulence theory.

REFERENCE STYLE
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KEYWORDS
Fermi-Pasta-Ulam-Tsingou problem, thermalization

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DeepSeek-Assisted Physics Instructional Design: An Empirical Study of Teaching Newton's Third Law in a High School Setting

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ABSTRACT

Generative artificial intelligence (GenAI) has shown growing potential in supporting teacher education, yet little is known about how pre-service teachers collaborate with AI during instructional design (ID). This study examined the effects of DeepSeek, a Chinese large language model, on pre-service physics teachers' ID performance and cognitive processes. A quasi-experimental design was conducted with 220 participants completing a 45-minute ID on Newton's Third Law, either with or without DeepSeek assistance. Data from IDs, interaction logs, and interviews were analyzed through statistical tests, Epistemic Network Analysis (ENA), and thematic coding. Results indicated that the DeepSeek-assisted group outperformed the control group in analytical and structural aspects of ID, such as Teaching Content Analysis and Learner Analysis. ENA revealed that high-performing participants exhibited proactive "problem representation–AI interaction–monitoring" patterns while low-performing participants relied on reactive prompting. Interviews further confirmed that AI was helpful in contextual introductions and experiment design but also revealed issues such as outdated curriculum references and overly absolute expressions that lacked sensitivity to teaching contexts. The findings suggest that GenAI can serve as a cognitive scaffold when used strategically and highlight the need to integrate AI literacy and metacognitive training into teacher education.

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Beyond Constant-Temperature Reservoirs: A Stirling Cycle with Constant Heat-Generation Rate

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ABSTRACT

Conventional heat-engine models typically assume two reservoirs at fixed temperatures, whereas radioisotope power systems provide heat at a constant generation rate rather than a constant temperature. We develop a theoretical framework for finite-time heat engines operating between constant heat-generation-rate hot sources and constant-temperature cold reservoirs, establishing a universal relation between average power and efficiency that is independent of engine cycle or working substance. As an illustrative example, we analyze a finite-time Stirling cycle with different control protocols, and find the match between our predicted efficiency and that of practical data. We also quantify the long-term performance degradation due to radioactive decay. This work introduces a new prototype for heat-engine theory and offers guidance for analyzing and designing radioisotope power systems.

ABSTRACT TOPIC

- Energy efficiency and retrofitting

KEYWORDS

Radioisotope power systems, Constant heat-generation-rate, Power-efficiency relation, Control protocols, Long-term performance degradation

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Statistics of Fluctuations in Anderson Localization

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ABSTRACT

The fluctuations of the wave density logarithm in a two-dimensional Anderson localized wave packet are shown to obey the key features of Kardar-Parisi-Zhang (KPZ) universality class. The fluctuations in localized wavepacket dynamics are found to exhibit an algebraic scaling with distance from the localization centre, characterized by an exponent of 1/3, and follow the Tracy-Widom distribution. Within a directed polymer picture of KPZ physics, one can also identify the dominant contribution of a directed path to the wave packet density and find that its transverse fluctuations are characterized by a roughness exponent 2/3. Leveraging on this connection with KPZ physics, we verify that an Anderson localized wave packet in 2D exhibits a stretched exponential correction to its well-known exponential localization. Together with extensive analysis of eigenstates in 2D Anderson problem, our results establish a unified KPZ framework for describing fluctuations and microscopic organization in 2D Anderson localization, revealing the glassy nature of localized states and providing new understanding into the universal structure of disordered quantum systems.

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KEYWORDS

Anderson localization, KPZ physics, fluctuation statistics, disordered systems.

Title: Illuminating the Cosmic Web: The Origins of Mpc-scale Magnetism and Giant Radio Emission

Abstract: The intracluster medium (ICM) is a turbulent, multi-phase, and magnetized environme that serves as a vital bridge within the cosmic web. It hosts vastly different gas phases, from co dense clouds to hot, tenuous plasma. Magnetic fields permeate this environment, regulating t physical processes that drive galaxy evolution—from the transport and acceleration of cosmic rays the multiphase structure of galaxy clusters. Despite their importance, the origin, amplification, a three-dimensional structure of these fields remain among the most enduring mysteries in extragalac astrophysics. In this talk, I will present innovative methods to probe intracluster magnetism and interplay with ICM turbulence. I will introduce new multi-wavelength diagnostic framewor incorporating machine learning algorithms to leverage radio and X-ray data for reconstructing the structure and strength of these fields. Applying these tools to MeerKAT observations, we ha mapped the Mpc-scale magnetic fields of several massive clusters, including the extreme merger Gordo, providing direct evidence of turbulence-driven dynamo amplification. Finally, I will discu how upcoming surveys from LOFAR, the Square Kilometre Array (SKA), and ngVLA, w revolutionize our understanding of cosmic magnetism, opening a new observational window into t origins of large-scale radio emission and the magnetic history of the universe.

On the Stochastic Thermodynamics of Moving Bodies

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ABSTRACT

The principle of covariance, a cornerstone of modern physics, asserts the equivalence of all inertial frames of reference. Fluctuation theorems, as extensions of the second law of thermodynamics, establish universal connections between irreversibility and fluctuation in terms of stochastic thermodynamic quantities. However, these relations typically assume that both the thermodynamic system and the heat bath are at rest with respect to the observer, thereby failing to satisfy the principle of covariance. In this study, by introducing covariant work and heat that incorporate both energy-related and momentum-related components, we promote fluctuation theorems into covariant forms applicable to moving thermodynamic systems and moving heat baths. We illustrate this framework with two examples: the work statistics of a relativistic stochastic field and the heat statistics of a relativistic Brownian motion. Although our study is carried out in the context of special relativity, the results can be extended to the nonrelativistic limit. Our work combines the principle of covariance and fluctuation theorems into a coherent framework and may have applications in the study of thermodynamics relevant to cosmic microwave background as well as the relativistic hydrodynamics for heavy-ion collisions.

REFERENCE STYLE

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KEYWORDS

Fluctuation Theorems, Covariance principle, Special Relativity, Stochastic Thermodynamics

Current-driven Archimedes chiral molecular motor

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Single-molecule junctions serve as an ideal platform for understanding nonequilibrium statistical and thermodynamic processes at small scales. Even at the single-molecule level, transport properties of molecules can be influenced by various degrees of freedom, such as molecular vibrons, localized plasmons, and spins, either within the molecule itself or in the surrounding environment. Studying these interactions and the accompanying energy conversion processes can enhance our understanding of fundamental small-scale thermodynamics and nonequilibrium statistics, while also expanding the functionality of single-molecule junctions in basic research. This talk will focus on the heat and work processes between electrons and atomic degrees of freedom molecules, focusing on theoretical design and experimental realization of a current-driven chiral molecular motor, akin to Archimedes screw.

Time-Optimal Qubit Reset Enabled by Structural Environment Spectrum

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ABSTRACT

A serious tension may exist between the quantum computation and erase processes, the former (latter) aims to enable more logical gates (restore the qubit with shorter time) requiring low (high) decoherence rate, which is determined by the coupling to the environment. To resolve such tension, we develop a switch-restore-switch scheme to minimize the reset time, where the qubit is switched from the low-decoherence configuration for computation to a fast-decoherence one for restoring. We implement the current scheme in the superconducting qubit with 4 representative environments. The shortest reset time is shortened from $\gtrsim$ 100 ns to 20 ns, which is as short as 0.4 times the typical two-qubit gate time. The current scheme shall provide an efficient way to reuse qubits in the current era with a limited number of qubits.

REFERENCE STYLE

Time-Optimal Qubit Reset Enabled by Structural Environment Spectrum, *[unpublished]*, 2026, Hong-Bo Huang, Hui Dong

KEYWORDS

Fast qubit reset, Structural environment spectrum, Superconducting qubit

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ASSESSING CONCEPTUAL UNDERSTANDING OF ENERGY IN ELECTROSTATIC FIELDS: A CONCEPTUAL FRAMEWORK-BASED STUDY OF CHINESE HIGH SCHOOL STUDENTS

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ABSTRACT

In physics education reform, conceptual understanding is foundational to developing students' core physics literacy. However, students often rely on "problem-solving templates" for specific scenarios rather than achieving deep conceptual mastery. This challenge is particularly acute in understanding energy in electrostatic fields, where abstract and complex conceptual chains frequently lead to persistent misconceptions. This study develops a comprehensive conceptual framework for electrostatic energy that integrates physical laws, situational features, reasoning processes, and task objectives. Using this framework, we designed and validated a multiple-choice assessment tool to investigate students' understanding through knowledge integration and context dependency. Employing a mixed-methods approach with Chinese high school students who completed the electrostatic field unit, we identified and characterized cognitive profiles across three proficiency levels: Novice, Intermediate, and Expert. Empirical results reveal that the framework effectively characterizes significant differences in knowledge structures and thinking patterns across proficiency levels. Notably, most students exhibit substantial knowledge fragmentation and rely on memorization-based problem-solving, which impedes their ability to transfer concepts to novel contexts. These findings provide precise diagnostic information for physics instruction and offer significant pedagogical implications for optimizing instructional design of energy concepts in electrostatic fields.

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KEYWORDS
Conceptual understanding, Electrostatic field energy, Knowledge integration, Ass essment tool, Physics education

HIDDEN RISKS AND OPTIMIZATION SCHEMES FOR APPLYING "SYMMETRY" IN HIGH SCHOOL PHYSICS TEACHING IN CHINA

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ABSTRACT

In contemporary high school physics teaching in China, "as known from symmetry" is frequently taught to students as a convenient problem-solving skill to help them get answers faster. However, this oversimplified application which omits rigorous physical proofs easily traps students in a pattern of knowing the results without understanding the underlying mechanisms. Consequently, students become accustomed to relying on empirical intuition to comprehend physics, which hinders the development of physics ideas and scientific thinking. By providing rigorous physical proofs for common applications of symmetry in high school physics, and demonstrating symmetry from the perspective of physical laws rather than geometric intuition, teachers can expose students to the underlying logic of physics. This approach effectively fulfills the requirements for scientific thinking outlined in the physics core competencies in senior high schools. Furthermore, introducing analysis cases of non-ideal conditions and utilizing contrastive teaching methods can not only reinforce the prerequisites for the correct application of symmetry, but also highlight the rigorous logic inherent in physics, thereby further enhancing students' analytical capabilities.

Abstract Topic: Physics and Science Education

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KEYWORDS
Symmetry, Physics teaching, Scientific thinking

Quantum Griffiths singularity in superconductors: A 10-year overview

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ABSTRACT

For the first time, we experimentally discovered a new quantum phase transition, i.e. quantum Griffiths singularity, in two-dimensional superconducting thin films, which reveals the prominent influence of disorder and dissipation on quantum phase transitions and expands the universality class of quantum phase transitions. Over the past decade, this discovery has become a universal phenomenon across various two- and three-dimensional superconducting systems, and evolved into a paradigm for studying disorder-induced quantum phase transitions for both conventional and unconventional superconductors.

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KEYWORDS
Quantum Griffiths singularity, superconductor, quantum phase transition, disorder, dissipation

Electron Ion Collider Status

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ABSTRACT

The Electron–Ion Collider (EIC), being designed and constructed by Brookhaven National Laboratory in collaboration with Thomas Jefferson National Accelerator Facility and other partner institutions, is a next-generation particle accelerator that will collide electrons with protons and atomic nuclei to image their internal structure with unprecedented precision. The collider will operate with polarized electron and hadron beams over a center-of-mass energy range of 20–140 GeV. In these collisions, the electron beam acts as a well-controlled probe that scatters from the quarks and gluons inside nucleons and nuclei, enabling detailed measurements of how these constituents are distributed and how they move and interact. Through these studies, the EIC will address fundamental questions about the dynamics of the strong nuclear force, the role of gluons in building the mass and structure of visible matter, and the origin of nucleon spin. This talk will present an overview of the EIC design and the current status of its construction at Brookhaven National Laboratory.

REFERENCE

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KEYWORDS

Electron Ion Collider, nuclear physics, accelerator, proton, electron

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PROBING ATOMIC- SCALE SURFACE ELECTROSTATIC FIELDS WITH AN ULTRAFAST MOLECULAR QUANTUM SENSOR

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ABSTRACT

The surface electrostatic field is the fundamental driving force behind surface interactions, governing adsorption, charge transfer, and surface reactivity. However, direct probing of such electrostatic fields at the atomic scale remains a major challenge. The combination of scanning tunneling microscopy (STM) with ultrafast terahertz (THz) pulses has opened new frontiers in probing dynamics at the atomic scale. In this talk, I will present our study on probing the atomic-scale distribution of surface electrostatic fields via the quantum coherence of single hydrogen (H_2) molecules trapped within an STM tunnel junction. We show that the H_2 molecule behaves as a two-level system (TLS) within the double-well potential defined by the tip and surface. By coupling ultrafast terahertz pulses into the tunnel junction, we drive coherent oscillations between the molecule's quantum states. Using THz pump-probe rectification spectroscopy, we successfully resolve the temporal evolution of this coherent superposition with femtosecond resolution. We find that the coherent oscillation frequency and decoherence time (T_2) are intrinsic to the local environment, varying significantly with tip position, tip-sample distance, and DC electric field. By tracking these dynamics across the surface, we achieve sub-angstrom spatial resolution of the surface electrostatic field distribution in real space. These results highlight a powerful quantum sensor for imaging the atomic-scale electrostatic potential landscape in low-dimensional systems.

KEYWORDS

THz-STM, Quantum sensing, Surface electrostatic field, Quantum coherence, Hydrogen molecule

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QUANTUM MANIPULATION OF ULTRACOLD ATOMS

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ABSTRACT

Manipulating quantum phenomena of microscopic particles to emulate novel states ofmatter and establish high-precision time standards promises to greatly advance futuretechnological developments. Techniques involving ultracold atoms have formed anexus between disciplines such as quantum information science, condensed matterphysics, and quantum precision measurement, positioning them at the forefront of hotresearch areas in physics. In the field of quantum metrology, ultracold atomic opticallattice clocks have achieved the highest time measurement accuracy to date. To overcomelimitations such as gravitational fluctuations in terrestrial and near -Earth environments, there is an urgentneed to develop optical frequency standards based on high-orbit space platforms. Ultracold atomicoptical lattice clocks on medium -to-high orbit space platforms, integrated with quantum communicationand time-frequency transter technologies, will enable precise star -to-ground clock comparisons andbecome a key component in the next generation of optical clock -based second definitions. On the otherhand, in quantum simulation, systems comprising hundreds up to millions of atoms can be artificiallcreated and controlled to mimic complex systems found in condensed matter physics and quantum fieldtheory. This facilitates the validation or prediction of novel quantum phenomena, exploration of theunderlying microscopic mechanisms, and fosters the next generation of technological and industrialrevolutions. Utilizing small-scale and manageable ultracold fermionic systems, important unsolved modelsin condensed matter physics like the Fermi-Hubbard model can be simulated, aiming to acquire phasediagrams of strongly correlated fermionic systems at low temperatures. In this talk, I will introduce thelatest developments in quantum manipulation based on ultracold fermionic systems for quantummetrology and quantum simulation in USTC.

KEYWORDS

Quantum metrology, Optical clock, Quantum simulation, Optical lattices

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Deterministic domain switching and magnetically switchable quantum geometric photocurrents in a Van der Waals antiferromagnet

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ABSTRACT

Antiferromagnets (AFMs) have also attracted enormous interest recently in spintronics due to the absence of stray fields and their terahertz resonant frequency. Despite the great advantages of antiferromagnetic spintronics, controlling and directly detecting antiferromagnetic order and other emergent order in 2D materials have been challenging. In my talk, I will focus on the Neel order in 2D AFMs (MnPS3 and MnPSe3). I will show that we have developed a sensitive second harmonic generation (SHG) microscope and detected long-range Neel antiferromagnetic (AFM) order down to the monolayer in MnPSe3 and the bilayer in MnPS3. In MnPSe3, we observed the switching of an Ising-type Neel vector reversed by the time-reversal operation. We rotated them by an arbitrary angle irrespective of the lattice by applying uniaxial strain. I will also talk about novel nonlinear optical response of MnPSe3 and MnPS3 to external fields such as spatially variant strain and magnetic field.

In non-centrosymmetric materials, light can be rectified into two types of DC photocurrents, known as injection and shift currents. Recent theory has uncovered their deep relation with the two-state quantum geometry of resonant transitions: In non-magnetic crystals, where these currents have been routinely observed, the injection current responds to circular light and probes the Berry curvature, while the shift current responds to linear light and probes the geometric connection. Magnetic crystals have been predicted to show a new set of hitherto unobserved magnetically switchable photocurrents, with the roles of linear and circular light interchanged: A linear injection current, which probes the quantum metric, and circular shift current, which probes the geometric torsion. In this second part, I will present the existence of such currents in the van der Waals antiferromagnet, demonstrating the switching of the current by flipping the Néel vector deterministically.

REFERENCE STYLE

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[6] Ni… Wu arXiv:2308.07249

KEYWORDS
Antiferromagnetic Domain Switching, Photocurrent, Quantum Geometry

Chiral phonons and emergent novel effects

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ABSTRACT

Phonons were traditionally considered as linearly polarized. Recently we predicted that phonons can be chiral and have angular momentum both in magnetic and nonmagnetic systems. The nondegenerate chiral phonons are also predicted and easily tuned in graphene/hexagonal Boron Nitride heterostructures. The chiral phonons were observed in monolayer tungsten diselenide, where the phonon chirality was confirmed by the infrared circular dichroism arising from pseudoangular momentum conservation. Our further experiments showed that through the emission of a chiral phonon the momentum-dark intervalley exciton is brightened and chiral phonons can have entanglement with photons. Recently, we predicted that the chiral phonons can propagate along high-symmetry axis of 3D materials, and can show a diode effect in chiral systems, and can induce high-temperature superconductivity. We also observed a chiral-phonon-activated spin-Seebeck effect in chiral materials very recently.

KEYWORDS

Chiral phonons

Stoichiometric FeTe is a Superconductor

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ABSTRACT

Iron-based superconductors are a fascinating family of materials in which multiple electronic bands and strong antiferromagnetic (AFM) correlations are key ingredients for competing ground states, including antiferromagnetism, electronic nematicity, and unconventional superconductivity. This framework for understanding unconventional superconductivity likely extends to a broad range of correlated quantum materials. However, it remains a grand challenge to understand how and why different competing orders emerge in a unified picture. FeTe, unlike its superconducting isostructural counterpart FeSe, has long been regarded as a AFM metal sans superconductivity. In this work, we employ molecular beam epitaxy to grow FeTe films and perform post-growth annealing under a Te flux. By performing spin-polarized scanning tunneling microscopy and spectroscopy (STM/S), we demonstrate that the AFM order in as-grown FeTe films is induced by interstitial Fe atoms that disrupt the ideal 1:1 stoichiometry. Remarkably, the removal of these interstitial Fe atoms through Te annealing yields stoichiometric FeTe films that show no AFM order and instead exhibit robust superconductivity with a critical temperature of ~13.5 K. This superconducting state is further confirmed by the observation of Cooper pair tunneling, zero electrical resistance, and the Meissner effect. Therefore, our results demonstrate that stoichiometric FeTe is inherently a superconductor, overturning a long held view that it is an AFM metal. This work clarifies the origin of superconductivity in FeTe-based heterostructures and demonstrates the importance in controlling stoichiometric disorder in understanding the competition between AFM and unconventional superconductivity in iron-based superconductors.

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Water and ice under extreme confinement

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ABSTRACT

When water is confined to spaces just a few molecules wide, it behaves nothing like the bulk water. For example, it can exhibit enhanced nuclear quantum effects (NQEs), ultrafast transport, anomalous dielectric constant, ferroelectricity and so on. However, the microscopic origin of those anomalous properties is still under debate. Recently, we have combined scanning probe microscopy and quantum sensing to probe the structure and dynamics of water under nanometer- and ångström-scale 2D confinement. We observed a critical confinement size of ~1.6 nm, below which the water diffusion is significantly suppressed, and the hydrogen-bonding network of water shows an 2D "ice-like" ordered structure. This result gives the compelling evidence for the liquid-to-solid transition induced by strong confinement at the ambient condition. Furthermore, we found that the 2D water can show symmetric hydrogen bonds and exotic superlubricity behavior. Those results may resolve the long-standing puzzle about the ultrafast water and ion transport under extreme confinement, which can potentially lead to revolutionary applications in desalination, energy storage, and nanofluidics.

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KEYWORDS

Water, Confinement, Phase transition, Superlubricity, Nuclear quantum effects

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The Kai Protein Biological Clock Synchronization Mechanism

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ABSTRACT

This paper systematically investigates the synchronization mechanism of the cyanobacterial Kai protein circadian clock, aiming to reveal the physical essence of the cooperative phosphorylation/dephosphorylation of KaiC proteins from the perspective of microscopic interactions. The article begins by reviewing the ubiquity and significance of synchronization phenomena in complex systems science, highlighting that "correlations" among individuals are key to understanding emergent behavior. In terms of theoretical modeling, this paper introduces the BBGKY hierarchy as a statistical physics tool, deriving the evolution equations for one-body and two-body distribution functions from the Liouville equation. Taking the "altruistic resource-sharing" model as an example, it rigorously derives the model's dynamical equations and finds that its first and second levels of the BBGKY hierarchy are decoupled. This indicates that the model fails to genuinely characterize the correlations among KaiC proteins and thus cannot reveal the physical essence of synchronization. To further explore the correlation mechanisms underlying synchronization phenomena, this paper introduces the Kuramoto model to investigate the collective synchronization behavior of coupled oscillator systems, offering a new theoretical perspective for understanding the phase synchronization among KaiC proteins. This work provides a new analytical framework for theoretical research on the synchronization mechanism of the Kai protein circadian clock and offers methodological insights for the physical modeling of emergent phenomena in complex systems.

Abstract Topic

The Synchronization Mechanism of the Kai Protein Biological Clock

REFERENCE STYLE

UnPublished

KEYWORDS

synchronization phenomenon, Kai protein circadian clock, correlation, BBGKY hierarchy, Kuramoto model

Advanced Thermal Management Materials for Electronic Packaging

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ABSTRACT

Thermal Interface materials (TIMs) are indispensable materials for heat dissipation and thermal management of modern electronics [1]. In this talk, I will report some most recent developments of the TIM by using liquid metal (LM) [2-4].

First, I will report a flexible LM@GN/ANF films are made by coating LM nano-droplets with graphene nanosheets (GN) via sonication, and then they are combined with aramid nanofibers (ANF). The LM@GN/ANF film is found to have a thermal conductivity of 5.67 W m^{-1} K^{-1} and a 24.5% reduction in Young's modulus,

Secondly, I will report a flexible composite TIM which enables magnetic field-triggered direction to change of heat flow, namely, the TIM acts effectively as a thermal switch. The material consists of liquid metal@nickel (LM@Ni) networks and diamond microparticles embedded in a polydimethylsiloxane (PDMS) matrix. The LM@Ni achieves both enhanced wettability on PDMS and magnetic responsiveness, while diamond provides the composite with high intrinsic thermal conductivity (13.92 $W \cdot m^{-1} \cdot K^{-1}$). Upon applying a magnetic field, the composite undergoes a rapid deformation, creating an “on” or “off” state with a switching ratio of 22.

Lastly, I will report how this Muti-functional TIM can be integrated into an all-solid-state elastocaloric cooling prototype.

Our work not only extends the application of TIM but also bridges compact solid-state cooling with efficient thermal management, establishing a new paradigm for TIM in smart thermal management applications [4].

REFERENCE STYLE

Paper Title, *Journal Name*, Volume Number, Page Numbers, Year of Publication, Initial1. LastName1, Initial2. LastName2, Initial3. LastName3, Initial4. LastName4.

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KEYWORDS
Thermal Interface materials, thermal management, liquid metal, Muti-functional TIM

MECHANISM OF SYMMETRY RESTORATION IN TURBULENT RAYLEIGH-BÉNARD CONVECTION

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ABSTRACT

Symmetry breaking is a ubiquitous phenomenon occurring in nature and is a cornerstone in modern physics. An example of spontaneous symmetry breaking in fluid turbulence is the existence of a single-roll large-scale flow structure in turbulent thermal convection, rather than an axisymmetric one expected from the symmetry of the system. However, it was recently discovered that the axisymmetric flow structure can be restored when a minute amount of polymer additives is introduced [1]. Although this symmetry restoration is accompanied by an anisotropic suppression of velocity fluctuations, it remains unclear whether such anisotropy is the cause or a consequence of the symmetry restoration. To resolve this question, we perform a series of numerical simulations of Rayleigh–Bénard convection incorporating both isotropic and anisotropic large-scale friction. Counterintuitively, isotropic friction preferentially damps horizontal motions and can restore a symmetric flow state, which cannot be found in an anisotropic friction case. These comparative simulations demonstrate that anisotropic suppression is a consequence rather than the cause of symmetry restoration. Additional simulations further show that the restoration cannot be attributed to flow laminarization either. We notice that flow symmetry restoration in turbulent thermal convection requires an orienting mechanism, for which buoyancy serves as a natural candidate. By comparing polymer-laden experimental data with numerical simulations employing large-scale friction, we find a common signature of buoyancy predominance in both systems, manifested by an enhanced and nearly time-symmetric velocity–temperature correlation. As buoyancy becomes predominant, the velocity field is slaved to buoyancy, leading to a buoyancy-aligned flow structure. We conclude that this buoyancy-dominated regime provides a necessary mechanism for restoring flow symmetry in turbulent thermal convection [2].

We gratefully acknowledge support of this work by the National Natural Science Foundation of China through Grants: 12232010, 12594530010, 12595302.

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KEYWORDS
Spontaneous symmetry breaking, symmetry restoration, turbulent flows

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Superconducting qubit devices and their computational applications

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ABSTRACT

Superconducting qubits provide a promising platform for a wide range of computational tasks, including the realization of fault-tolerant logical qubits for universal quantum computing, the simulation of nonequilibrium phenomena in quantum many-body systems, and the solution of combinatorial optimization problems in practical applications. In this talk, I will introduce the various types of superconducting qubit devices currently being developed at Zhejiang University. In particular, I will outline our design principles, which aim to achieve a balanced improvement in performance by jointly optimizing key metrics such as qubit number, coherence, and gate/readout speed and fidelity. These devices are fabricated using a flip-chip architecture, where frequency-tunable transmon qubits and couplers are integrated on a substrate separated from the control and readout wirings. The couplers are transmon-based with long-range arms, enabling direct two-qubit gates between distant qubits. I will also present our experimental progress using these devices in quantum error correction, the simulation of topological phases, and the performance benchmarking of a hybrid quantum-classical search algorithm aimed at demonstrating quantum advantage.

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Combinatorial optimization enhanced by shallow quantum circuits with 104 superconducting qubits, *National Science Review*, nwag124, 2026, X. Zhu *et al.*

KEYWORDS

Superconducting qubit, Superconducting quantum device, Quantum simulation, Quantum algorithm

PRACTICAL EXPLORATION OF HIGH SCHOOL PHYSICS "PROJECT-BASED RESEARCH" WITH PBL-PAD CLASSROOM TEACHING MODEL

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ABSTRACT

The main content of this research is "Project-based research" to address the problems that exist universally in traditional experimental physics education. We created an innovative "PBL-PAD classroom" teaching model by combining practicability of project learning and the structural advantage of PAD (Presentation-Assimilation-Discussion) teaching model. This model has been explored through four stages of education.

This study adopts an experimental design. First, we chose M and N classes from F high school in Shanghai to conduct basic educational practice of PBL-PAD classroom research, and conducted a questionnaire survey. We used a five-point likert scale adapted from the ILS questionnaire to evaluate the learning style of students. Based on the classification of core physics literacy outlined in the *General High Schools Physics Curriculum Standards*, we used an evaluation scale to examine changes in core competence. The change of students' physical and objective grades can be reflected through the test questions based on adaptation of relevant questions from the real questions of provincial and municipal examination or college entrance examination.

The results of the study showed that experimental and control groups had a clear difference in objective physical performance after receiving the PBL-PAD classroom teaching model. There is a clear hierarchical phenomenon in the total scores of class X's and class Y's physical core abilities, and there is no obvious difference between physical concept, scientific thinking, scientific attitude and responsibility. However, significant differences have been found at the level of scientific inquiry. In terms of learning style, class X do not differ significantly in the number of students showing an active and reflective learning style or a sensing and intuitive learning style. However, there are clear differences in the distributions of visual versus verbal learners and

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sequential versus global learners, with the largest proportion of them being actively perceived.

REFERENCE STYLE

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KEYWORDS

Project-based learning, PAD classroom, High school physics

From Monte Carlo to nonequilibrium Green's functions

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ABSTRACT

I like to summarize and highlight 40 years of my research experience, from the well-known work on cluster algorithms (the Swendsen-Wang algorithm) to the nonequilibrium Green's functions (NEGF) for mesoscopic transport. Finally, I briefly outline the photon transport in nonequilibrium or Floquet-driven states.

Novel Phonon Thermal Transport in Quantum Two-Dimensional Materials

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ABSTRACT

The study of heat conduction in micro-nano materials has both practical application value and theoretical research value. With gradual shrinking of the size of current microelectronic devices, excessive heat will be locally generated and concentrated, which affects the performance and life of the devices. Thermal management at the nanoscale is therefore particularly significant. For both 1D and 2D materials, there exist theoretical calculations and experiments to verify the existence of anomalous heat conduction, and the physical mechanism is worthy of further study. This talk will present recent advances in phonon-mediated thermal conduction in 2D materials, with an emphasis on how nanostructuring, dimensionality, and defect engineering influence phonon transport. Special attention will be given to interfacial thermal transport between the 2D materials and various substrates, a bottleneck in nanoscale heat dissipation. Moreover, the presentation will explore thermal management strategies in 2D FETs, highlighting how optimized heat dissipation pathways can significantly enhance device stability and performance.

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KEYWORDS
Phonon transport, 2D, heat dissipations, low dimensional materials

ROLE OF EXCITATIONS IN SUPERCOOLED LIQUIDS

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ABSTRACT

One of the central open problems in condensed matter physics is to understand why glasses relax so slowly and eventually become rigid without developing crystalline order. A widely held idea is that relaxation is controlled by localized excitations, but identifying these excitations and determining how they contribute to dynamics has remained a major challenge.

Here we introduce an algorithm that extracts the elementary excitations of glasses over an unprecedented energy range, allowing us to directly characterize their density, geometry, and spatial organization. This makes it possible to address a key missing piece in the field: how these excitations, and the interactions between them, shape structural relaxation. We find that both the excitations themselves and their mutual interactions are strongly predictive of where and how relaxation occurs. Most strikingly, the geometry of the excitations reveals evidence for a dynamical transition, suggesting that this transition plays an important role in relaxation even deep in the low-temperature regime.

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KEYWORDS

Glass, Excitation, Landscape

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TWO ENERGY EXPRESSIONS REFLECT DIFFERENT SYSTEMS UNDERSTANDING

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ABSTRACT
Energy is an essential concept for physics and science education as it links diverse phenomena through conservation, yet students often describe energy changes by saying that energy "disappears" or is "used up". These expressions are usually treated as variants of the same misconception. In this study, we test a different hypothesis suggesting that they reflect distinct levels of systems understanding. We analyzed 2,310 item-level responses from think-aloud interviews with Grade 6, Grade 8 and university students (n = 165) across 14 everyday energy contexts. Using an interaction-based framework, we coded each response independently for its direct answer to the prompt "Where does the energy go?" and for the systems elements coordinated in the accompanying explanation. Response category and systems-understanding level were strongly associated, and the predicted pairings dominated the joint distribution (Cramer's V = 0.627; 73.9% observed versus 28.5% expected under independence). Explicit interaction contexts increased scientifically normative responses overall, but this advantage was explained by stronger systems understanding, especially in Grade 8 when such understanding was solidly forming. After accounting for systems understanding, context was no longer clearly associated with response category. The results show that two classic energy expressions are not equivalent misconceptions, but markers of different representational states with direct implications for assessment and instruction.

KEYWORDS
Energy change, Systems understanding, Misconception, Physics education, Assessment

RESEARCH ON PROMOTING DEEP LEARNING IN HIGH SCHOOL PHYSICS BASED ON COMPLEX PROBLEM SITUATIONS

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ABSTRACT

In physics education, students learning in complex problem situations has been widely recognized as challenging, with instruction often remaining fragmented and superficial when addressing real-world problems, making it difficult to promote deep learning. To address this deficit, this study develops a teaching model for high school physics driven by complex problem situations, grounded in a conceptual framework that integrates deep learning principles with structured problem-solving processes. The proposed model consists of six interconnected components: creating problem situations, deconstructing problem chains, building learning scaffolds, forming solutions, constructing knowledge systems, and applying knowledge transfer. Guided by this model, we implemented a quasi-experimental design with three rounds of intervention, assessment, and optimization, using a combination of quantitative and qualitative measures to assess students' deep learning levels and thinking structures. The assessment results show that the experimental group significantly outperformed the control group in deep learning motivation, strategies, and thinking structures, particularly at the relational and extended abstract levels of the SOLO taxonomy, as well as in scientific inquiry, collaboration, and problem-solving performance. These findings indicate that the proposed teaching model can effectively represent and enhance students' deep learning development, providing a useful framework for physics instruction aimed at fostering integrated knowledge and higher-order thinking.

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KEYWORDS
Physics education, Teaching model, Deep learning,Complex problems, Situational teaching

Achievement, Community, Transformation:

How Travel Grants Impact Physics Careers in the Global South

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ABSTRACT

The International Union of Pure and Applied Physics (IUPAP) Working Group 5: Women in Physics (WG5) was established as a resolution at the 1999 General Assembly in Atlanta, Georgia, "to survey the present situation and report to the Council and the Liaison Committees, and to suggest means to improve the situation for women in physics". Since March 2002, WG5 has convened eight triennial events, the International Conference for Women in Physics (ICWIP), and supported yearly travel grants to young women physicists from the Global South.

For this paper we present preliminary data on the impact of IUPAP's investments in 860 travel grants, with recipient selections made by WG5. Initially, applicants from Eastern Europe dominated the applicant pool; but during the last fifteen years women from the Global South—Argentina, Brazil, India, Kenya, Pakistan—predominated. Herein we will present survey and interview data on the impact of travel grants on recipients' career trajectories, contextualized within national, regional, and global efforts to increase gender equity in physics.

Survey data are analyzed using basic descriptive statistics, and where possible contrasts were made between subpopulations. Interview data are analyzed using an open coding process, allowing our interpretations to rely on respondents own words. We apply Angela Johnson's 2020 model of intersectionality as methodology to center grant recipients as knowers rather than mere sources of data, giving them meaningful roles in naming what matters, in co-constructing interpretation, and in shaping how findings are interpreted. This is a justice-oriented approach that will attend to acts of refusal, resilience, and collective care as important units of analysis.

Findings reveal that travel grants make demonstrative impacts on women's physics careers. They have engendered community building among women scientists, helped recipients create productive partnerships across national and regional borders, and provided women with leadership opportunities within their home countries.

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KEYWORDS
Women, Global South, Physics, Careers, Travel Grants

Time-optimal Qubit Reset via Environmental Spectral Structure

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ABSTRACT

Fast qubit reset is essential for qubit reuse in the noisy intermediate-scale quantum computing era, yet it conflicts with the weak decoherence required for high-fidelity computation. We solve the time-optimal reset problem for a frequency-tunable qubit coupled to a structural environment under realistic spectral and control constraints. The optimal strategy consists of a switch–restore–switch sequence, where the qubit is moved from a low-decoherence computational configuration to a high-decoherence restoring configuration and then returned for reuse. For superconducting qubits in four representative environments, this strategy reduces the reset time from typically $\gtrsim 100$ ns to 20 ns, about 40% of a typical two-qubit gate time, while achieving a reset precision of 10^{-5}. Our results identify environmental spectral structure as a practical resource for rapid, high-fidelity qubit reset and provide a design principle for qubit reuse on qubit-limited processors.

REFERENCE STYLE

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KEYWORDS

Qubit reset, Mid-circuit reset, Time-optimal control, Superconducting qubit, Spectral engineering,

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The Dynamic Process of Human-AI Collaboration among College Students in Solving Open-ended Mechanics Problems

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ABSTRACT

Recent advances in generative artificial intelligence (AI) have raised important questions about its role in supporting students' problem solving in physics. While much existing research has focused on AI's accuracy in producing solutions, less is known about how students may strategically collaborate with AI tools during authentic problem-solving processes. This study examines undergraduate students' interactions with DeepSeek, a reasoning-oriented large language model, as they engaged in solving physics problems designed with rich context and open-ended tasks. The results reveal clear group differences: low-performing students often relied on AI for direct answers, medium-performing students partially integrated AI feedback, while high-performing students engaged in iterative cycles of questioning, interpretation, and self-construction. These findings suggest that the effectiveness of human-AI collaboration in physics problem-solving depends not only on the availability of AI but also on students' ability to critically and productively engage with AI outputs. The study contributes to a deeper understanding of the dynamics of human-AI problem-solving and offers implications for instructional design aimed at fostering effective AI use in physics education and beyond.

KEYWORDS

Problem solving, Human-AI collaboration, Cognitive offloading

Granular gas thermodynamics

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ABSTRACT

Granular gas is a physical system formed by random collisions of macroscopically nearly identical particles driven by a vibrating plate. Due to the randomness of collisions, granular gas exhibits stochastic motion similar to that of microscopic molecules. Therefore, on one hand, granular gas can serve as a thermal bath with certain thermodynamic properties such as a temperature and pressure, driving the random motion of asymmetric Brownian motors and enabling the exploration of stochastic thermodynamic principles, including entropy increase laws and fluctuation theorems. On the other hand, as a natural model system of hard-sphere matter, granular gas itself can be regarded as a small thermodynamic system of hard-spheres. Thus, after carefully addressing various non-ideal factors in experiments, granular gas becomes a natural platform for exploring the thermodynamic laws of small systems.

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KEYWORDS

Granular gas, hard sphere system, small system, thermodynamics

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KEYWORDS
Generative artificial intelligence, Instructional design, DeepSeek, Newton's Third Law, Pre-service teachers

Finite-Time Thermodynamics Perspective into Nuclear Power Plant Heat Cycle

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ABSTRACT

Nuclear power plants are representative heat-to-work conversion systems, and improving their thermodynamic performance is essential for cost-effective low-carbon energy supply. Classical thermodynamics provides an upper bound on efficiency, but offers limited guidance when power output is the primary concern under realistic finite-rate heat transfer. In this work, nuclear power plant heat cycles are revisited from the perspective of finite-time thermodynamics. First, the structural evolution and efficiency characteristics of nuclear power plants across four generations are reviewed, showing that gross efficiency generally increases with Carnot efficiency and is strongly associated with higher coolant outlet temperature. A finite-time model is then developed for the Brayton cycle without phase transition and for the Rankine cycle with liquid-vapor phase transition. For the Brayton cycle, the analysis recovers the Curzon-Ahlborn efficiency at maximum power. For the Rankine cycle, the model explicitly incorporates phase transition and reveals an intrinsic trade-off between output power and efficiency. Numerical calculations based on representative nuclear-power-plant conditions further show that the mass flow rate, high-temperature pressure, and phase-change properties of the working fluid substantially affect the attainable power-efficiency domain, with identifiable optimal operating conditions for maximum power. These results provide physical insight and a practical framework for optimizing nuclear power plants and other Rankine-type energy-conversion systems.

REFERENCE STYLE

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KEYWORDS

nuclear power plants, finite-time thermodynamics, Rankine cycle, power-efficiency trade-off

THREE FORMS OF ENACTED PCK IN PHYSICS TEACHING: TRANSFORMATIONS OF REPRESENTATION, LOGICAL STRUCTURE, AND MEANING OF PHYSICS KNOWLEDGE

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ABSTRACT

Traditionally, descriptive assessments of teachers' pedagogical content knowledge (PCK) have focused primarily on "what teachers ought to do" and "what teachers could do", while paying limited attention to "what teachers actually do" in classroom practice. Guided by the Refined Consensus Model (RCM), this study shifts the analytical focus toward the dynamic processes of teaching, examining how physics teachers mobilize, integrate, and transform subject matter knowledge in real time to address specific instructional challenges and achieve instructional goals. Based on an empirical analysis of multi-source data from 19 physics teachers, three categories of enacted PCK (ePCK) were identified: (1) transformation of the representation of subject matter knowledge, involving the activation of static symbols into dynamic sensory experiences; (2) transformation of the logical structure of subject matter knowledge, involving the integration of fragmented information into coherent conceptual frameworks and the reconstruction of knowledge production processes; and (3) transformation of the meaning of subject matter knowledge, involving the restoration of condensed disciplinary knowledge to real-life contexts and the design of structured cognitive conflicts to facilitate conceptual change. By further considering the quality of classroom interactions and students' learning outcomes, these ePCK forms were categorized into low-, medium-, and high-quality levels. This study advances PCK research toward a more practice-oriented approach that foregrounds the dynamic nature of teaching and teachers' professional agency, while offering both reflective insights and practical implications for improving physics teaching and student learning.

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KEYWORDS
EPCK, Transformation of subject matter knowledge, RCM, Physics teacher

COMPARATIVE ANALYSIS OF THE NEW EDITION GRADE 7 SCIENCE TEXTBOOKS: EVIDENCE FROM LLM- AND HUMAN-BASED EVALUATION

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ABSTRACT

Traditional textbook evaluation methods face growing challenges as revision cycles shorten. Large language models (LLMs), with their capacities for semantic understanding and logical reasoning, offer a promising alternative; however, their reliability for such tasks remains insufficiently validated. This study employed both human raters and an LLM (Gemini-3-pro) to quantitatively analyze STEM-related content in the latest science textbooks from three major Chinese publishers. Human evaluation reveals that all three editions are science-centered in their STEM content distribution, with technology and mathematics primarily serving supportive roles. Engineering content shows the most notable variation across editions. Three-discipline integration is the most common interdisciplinary pattern. Comparing human and LLM performance, Gemini-3-pro demonstrates reproducible stability across repeated trials and achieves high precision but low recall, reflecting a conservative coding tendency. The model performs well when textual cues are explicit, but tends to miss content requiring contextual interpretation, particularly in the technology and mathematics dimensions, due to its reliance on surface-level semantic matching. Based on these findings, we propose a human–AI collaborative framework in which LLMs handle structured extraction and preliminary annotation, while human raters focus on boundary-ambiguous segments, thereby improving both efficiency and reliability.

KEYWORDS

STEM education, LLM, Science textbooks, Textbook analysis

LARGE LANGUAGE MODELS IN PHYSICS EDUCATION: FACTORS SHAPING UNCERTAINTY IN EXPLAINING PHYSICS PROBLEMS

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ABSTRACT

Large language models (LLMs) show considerable promise for educational question answering and learning support, yet their application in physics education remains constrained by output uncertainty. Physics problems involve strict conditional constraints, well-defined conceptual boundaries, and multi-step reasoning, making LLM-generated explanations particularly sensitive to subtle variations in external settings. Consequently, the same problem may elicit substantially different responses under different conditions, raising concerns about reliability and interpretability. This study investigates the factors shaping LLM uncertainty in explaining physics problems, focusing on prompt design, retrieval-augmented generation (RAG), and temperature settings. We systematically examine how these variables influence response uncertainty and use visualization methods to illustrate variation patterns across conditions. This research provides a basis for evaluating the quality of LLM applications in physics education, optimizing model deployment strategies, and improving intelligent instructional systems for discipline-specific learning contexts.

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KEYWORDS

physics education, large language models, uncertainty analysis, prompt design, retrieval augmentation

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ASSESSMENT OF KNOWLEDGE INTEGRATION IN STUDENT LEARNING OF GALVANIC CELL: AN INTERDISCIPLINARY APPROACH CONNECTING PHYSICS AND CHEMISTRY

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ABSTRACT
The galvanic cell is a typical interdisciplinary topic, which is primarily taught in chemistry but its underpinning is closely related to physics. Student learning in galvanic cell has been extensively studied in chemistry education, which has revealed a large number of misconceptions that are difficult to change through traditional instruction. A source of the learning difficulties is that most students lack an explanatory framework to integrate the many complex phenomena and processes into a coherent knowledge system. As a result, students often rely on memorization of terms, laws, and equations in solving problems but without meaningful understanding in their reasoning. To address the deficit in learning, this study aims to help students develop an explanatory framework for supporting an integrated knowledge structure. Specifically, a conceptual framework model about galvanic cell is developed based on the central idea from physics, which is used as the core concept for mechanistic explanations of the related chemistry concepts. Guided by the conceptual framework, an instrument is developed to assess the knowledge integration in student learning of galvanic cell. A combination of qualitative and quantitative measures were used to assess the levels of knowledge integration in learning galvanic cell with a large number of Chinese high school and college students. The assessment results show that the conceptual framework model can effectively represent the knowledge structures of students at different levels of knowledge integration. The galvanic cell conceptual framework and assessment results can provide useful resources for teachers to develop instruction for promoting knowledge integration.

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KEYWORDS
knowledge integration, galvanic cell, interdisciplinary learning, physics chemistry

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Cross Machine Tokamak Disruption Prediction: A Systematic Framework Driven by Physics-Guided Transfer Learning

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ABSTRACT

Realizing fusion energy requires not only high-performance plasmas but also the ability to maintain stable operation. In tokamaks, major disruptions are rapid terminations of plasma confinement, typically involving thermal quench and current quench, remain one of the main obstacles to safe tokamak operation. They can cause severe damage, long interruptions of operation, and major economic losses. Reliable early warning is therefore required for disruption mitigation and, where possible, avoidance in future devices. Data-driven predictors have shown strong performance, but their extension to large, high-parameter devices is limited by the scarcity of target-machine disruption data. Disruption data on large, high-parameter tokamaks are inherently scarce because deliberately accumulating disruptive shots to train a predictor risks severe damage to the machine. We present a systematic framework addressing this challenge through physics-guided transfer learning, using J-TEXT as the source platform, EAST for small-to-large-device transfer, and HL-2A for cross-regime studies at higher parameters. We developed single-device disruption predictors using both physics-guided feature extraction and deep architectures, demonstrating real-time density-limit disruption avoidance. We then studied transfer from J-TEXT to EAST, an ITER-like fully superconducting long-pulse tokamak, we studied transfer under deliberately limited target-machine data to simulate the conditions future large-device predictors will face, and extended this to adaptive prediction from the very first plasma discharge. On HL-2A, cross-regime transfer revealed that disruption precursor patterns are not universal. High-performance operational regimes exhibit distinct precursor signatures, requiring regime-aware transfer strategies rather than naive pooling of data from different regimes. Interpretability is used here not mainly to explain model outputs after training, but to study disruption physics from data, identify physically meaningful and transferable precursor information, and motivate physics constraints for prediction on data-scarce new tokamaks. Taken

together, these studies support a practical route toward transferable disruption prediction under the data constraints expected in future tokamaks.

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KEYWORDS

fusion energy, disruption prediction, transfer learning, interpretability, physics priors

Research on the Application of Virtual Simulation Technology in Physics Education

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ABSTRACT

This study explores the application effectiveness of virtual simulation technology in inquiry-based physics instruction, using the topic of ideal gases in junior secondary school physics as a vehicle. A virtual simulation tool for visualizing the motion of ideal gas molecules was designed and developed, enabling the simulation of molecular motion under adjustable parameters such as temperature and volume. Based on this tool, an inquiry-based lesson titled The Invisible "Gas Spirits" was designed for eighth-grade students, integrating elements such as engaging introduction, foundational knowledge building, virtual inquiry, and real-life applications to establish connections between microscopic and macroscopic understanding. Classroom assessment questions were developed, covering topics such as molecular thermal motion and the relationship between gas pressure, temperature, and volume. Data collected include students' hands-on operation data, assessment responses, video recordings, and classroom participation performance. Subsequent analysis will focus on the effectiveness of virtual simulation in enhancing students' conceptual understanding, students' inquiry abilities when manipulating different parameters, and the practical value of virtual demonstration technology in addressing instructional challenges related to microscopic physics concepts.

KEYWORDS

virtual simulation, physics teaching, gas molecular motion, physics education

Progress of the HEPS construction and commissioning

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ABSTRACT

The High Energy Photon Source (HEPS) is the first fourth-generation synchrotron radiation light source project in Asia, with an electron energy of 6 GeV, a circumference of 1360 m and a natural emittance of a few tens of picometers. As a green-field light source, the HEPS construction started in 2019 and is scheduled to be completed in 2025. Now civil construction, component fabrication and tunnel installation have been complected, and multipole milestones have been achieved in commissioning of the accelerator and beamlines. The HEPS pass the performance acceptance review in October 2025. In this paper, the construction process as well as the commissioning progress of the HEPS are reported, where the challenges faced and corresponding measures during the commissioning are introduced.

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KEYWORDS

High Energy Photon Source, Fourth-generation synchrotron radiation light source, construction, commissioning

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Finite-time thermodynamics: Integrating dynamics into thermodynamics

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ABSTRACT

The central objective of finite-time thermodynamics is to optimize the efficiency of energy conversion and utilization in processes carried out within finite durations. Classical thermodynamics usually assumes quasi-static processes that proceed infinitely slowly; however, in practical engineering systems and natural processes, rapid changes often occur over limited timescales, rendering the quasi-static assumption inapplicable. This report reviews the development of finite-time thermodynamics and then focuses on three representative topics: the power-efficiency trade-off in finite-time thermodynamic cycles, geometric optimization schemes for minimizing energy dissipation under finite-time control, and related experimental progress in the field.

KEYWORDS

finite-time thermodynamics, energy efficiency, power optimization, geometric control, experimental progress

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Fermion Sign Problem and Lee-Yang Phase Transition Theory

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ABSTRACT

To simulate indistinguishable particles, recent studies of path-integral molecular dynamics formulated their partition function Z as a recurrence relation involving a variable ξ , with $\xi = 1(-1)$ for bosons (fermions) [1-3]. Inspired by Lee-Yang phase transition theory, we extend ξ into the complex plane and reformulate Z as a polynomial in ξ [4]. By analyzing the distribution of the partition function zeros, we gain insights into the analytical properties of indistinguishable particles, particularly regarding the fermion sign problem (FSP). We found that at 0 K, the partition function zeros for N particles are located at $\xi = -1, -1/2, -1/3, ..., -1/(N-1)$. This distribution disrupts the analytic continuation of thermodynamic quantities, expressed as functions of ξ and typically performed along $\xi = 1 \rightarrow -1$, whenever the paths intersect these zeros. Moreover, we highlight the zero at $\xi = -1$, which induces an extra term in the free energy of the fermionic systems compared to ones at other $\xi = e^{i\theta}$ values. If a path connects this zero to a bosonic system with identical potential energies, it brings a transition resembling a phase transition. These findings provide a fresh perspective on the successes and challenges of emerging FSP studies based on analytic continuation techniques.

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KEYWORDS

Fermion Sign Problem, Lee-Yang Zeros, Phase Transition, Monte-Carlo

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Mesoscopic Fluctuations in Entanglement Dynamics

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ABSTRACT

Understanding fluctuation phenomena plays a dominant role in the development of many-body physics. The time evolution of entanglement is essential to a broad range of subjects in many-body physics, ranging from exotic quantum matter to quantum thermalization. Stemming from various dynamical processes of information, fluctuations in entanglement evolution differ conceptually from out-of-equilibrium fluctuations of traditional physical quantities. Their studies remain elusive. Here we uncover an emergent random structure in the evolution of the many-body wavefunction in two classes of integrable—either interacting or noninteracting—lattice models. It gives rise to out-of-equilibrium entanglement fluctuations which fall into the paradigm of mesoscopic fluctuations of wave interference origin. Specifically, the entanglement entropy variance obeys a universal scaling law in each class, and the full distribution displays a sub-Gaussian upper and a sub-Gamma lower tail. These statistics are independent of both the system's microscopic details and the choice of entanglement probes, and broaden the class of mesoscopic universalities. They have practical implications for controlling entanglement in mesoscopic devices.

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KEYWORDS

Quantum simulations, nonequilibrium quantum systems, entanglement dynamics, mesoscopic physics, quantum thermalization

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Deep Learning of Electronic Structure: Challenges and Opportunities

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ABSTRACT
First-principles electronic structure calculations have profoundly advanced research in physics, chemistry and materials science, yet their further development remains constrained by the accuracy – efficiency dilemma. In this talk, I will present recent breakthroughs in deep-learning methodologies aimed at overcoming this bottleneck, with an emphasis on deep-learning density functional theory for efficient and intelligent materials simulations. These advances extend the reach of first-principles calculations to unprecedented scales and complexity, enhancing the impact of quantum mechanics in scientific discovery.

Energy Transport in Superionic Crystals

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ABSTRACT

Compared with conventional solids such as crystalline silicon, the molecular structure of superionic crystals is special. The anions form a rigid sublattice while cations are highly disordered and superionic with liquid-like mobilities, which makes the transport property of superionic crystals nontrivial and forms a judicious platform to study unique energy exchange mechanism between the rigid sublattice and an ion-conducting subsystem. For example, researchers found that more than 87% of Li^+ ion diffusion in the superionic $Li_{3.042}Ge_{0.042}P_{0.958}O_4$ originates from less than 10% of the vibrations between 8 and 20 THz. For another example, our recent preliminary results indicate that thermal conductivity resulting from the diffusion of liquid-like cations in superionic Li_2S can contribute around ~30% of the total thermal conductivity, suggesting that thermal transport channels resulting from lattice vibrations and the diffusion of liquid-like cations should be considered. These unusual transport properties, which are strongly related to interactions between ions and vibrations in superionic crystals, however, have rarely been investigated. This is mainly because the conventional theory fails to treat systems with significant movement of ions. In this talk, I will introduce our developed methodology to quantify the detailed transport process in superionic crystals, and unveil the understanding mechanisms for the abnormal transport phenomena observed in superionic crystals.

REFERENCE STYLE

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KEYWORDS

Superionic crystals, ion transport, energy carriers

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Topside thermal mapping of phonon nonaquarium in-operando nanodevices by electronic Doppler broadening

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ABSTRACT

Localized hotspots and steep temperature gradients in nanoelectronics degrade performance and impede further device miniaturization. Imaging these nanoscale temperature fields in operando is essential for fundamentally understanding thermal transport and interfacial nonequilibrium in nanodevices and developing more effective thermal dissipation designs. Scanning transmission electron microscopy based thermometry methods, despite their high spatial resolution, cannot be used for regular devices as they require an ultrathin sample for electron transmission. Here we propose a generic topside nanoscale thermometry compatible with devices on regular thick substrates utilizing elastic energy spectroscopy of reflection electrons, termed Reflection Electron Elastic Energy Thermometry (REEET), which directly measures the mean kinetic energy of thermally vibrating atoms in materials. Local temperature is

measured by directly probing the mean kinetic energy of thermally vibrating atoms via the electronic Doppler broadening effect. The measurement principle is experimentally validated on diverse material types including graphite, Si_3N_4, and W, all showing good agreement with first-principles predictions. Using this technique, we visualized the phononic/lattice temperature field of several in operando carbon-based nanodevices, exhibiting a high spatial resolution of 14 nm. Furthermore, we experimentally reveal nonequilibrium thermal transport and anisotropic mode coupling across interfaces in Joule-heated nanodevices where Fourier's law breaks down, highlighting operando thermal imaging as essential for overcoming the heat dissipation bottlenecks in nanoelectronics. These results demonstrate that the present method, with its inherent topside imaging advantage and sample flexibility, could become a transformative tool for future nanoelectronics research and development.

KEYWORDS
Nonequilibrium phonon transport, electron-phonon coupling, nanoscale thermal transport, electron microscopy, nanoscale thermometry

FACIAL EXPRESSION RECOGNITION FOR PROBING STUDENTS' EMOTIONAL ENGAGEMENT IN SCIENCE LEARNING

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ABSTRACT

Student engagement in science classroom is an essential element for delivering effective instruction. However, the popular method for measuring students' emotional learning engagement (ELE) relies on self-reporting, which has been criticized for possible bias and lacking fine-grained time solution needed to track the effects of short-term learning interactions. Recent research suggests that students' facial expressions may serve as an external representation of their emotions in learning. Accordingly, this study proposes a machine learning method to efficiently measure students' ELE in real classroom. Specifically, a facial expression recognition system based on a multiscale perception network (MP- FERS) was developed by combining the pleasure-displeasure, arousal-nonarousal, and dominance- submissiveness (PAD) emotion models. Data were collected from videos of six physics lessons with 108 students. Meanwhile, students' academic records and self-reported learning engagement were also collected. The results show that students' ELE measured by MP-FERS was a significant predictor of academic achievement and a better indicator of true learning status than self-reported ELE. Furthermore, MP-FERS can provide fine-grained time resolution on tracking the changes in students' ELE in response to different teaching environments such as teacher-centered or student-centered classroom activities. The results of this study demonstrate the validity and utility of MP-FERS in studying students' emotional learning engagement.

REFERENCE STYLE

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KEYWORDS
Student engagement, Emotional learning engagement, Facial expression recognition, Science teaching

Experimental Quantum Thermodynamics using Nuclear Magnetic Resonance

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ABSTRACT

Classical thermodynamics studies macroscopic systems. In small-particle systems far from the thermodynamic limit, many concepts and issues in classical thermodynamics need to be redefined and explored due to the influence of quantum effects, gradually forming the emerging field of quantum thermodynamics. With the development of quantum information technology, many quantum systems can now be precisely controlled, providing an ideal platform for experimental research in quantum thermodynamics. In particular, as a highly controllable room-temperature spin ensemble system, nuclear magnetic resonance (NMR) offers unique advantages in the study of quantum thermodynamics. In this talk, I will first briefly review the basic principles of NMR and spin control techniques. Then, by utilizing two different quantum resources, namely indefinite causal order and three-body interactions, we can construct quantum versions of working substances and implement refrigeration cycles. Finally, I will present experimental results demonstrating a "quantum refrigerator with indefinite causal order" and a "self-contained quantum refrigerator" using NMR spin ensembles.

KEYWORDS

Quantum information, Quantum thermodynamics, Nuclear magnetic resonance

Operational Metric for Quantum Chaos and the Corresponding Spatiotemporal Entanglement Structure

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ABSTRACT

Chaotic systems are highly sensitive to a small perturbation, and are ubiquitous throughout biological sciences, physical sciences and even social sciences. Taking this as the underlying principle, we construct an operational notion for quantum chaos. Namely, we demand that the future state of a many-body, isolated quantum system is sensitive to past multitime operations on a small subpart of that system. By `sensitive', we mean that the resultant states from two different perturbations cannot easily be transformed into each other. That is, the pertinent quantity is the complexity of the effect of the perturbation within the final state. From this intuitive metric, which we call the Butterfly Flutter Fidelity, we use the language of multitime quantum processes to identify a series of operational conditions on chaos, in particular the scaling of the spatiotemporal entanglement. Our criteria already contain the routine notions, as well as the well-known diagnostics for quantum chaos. This includes the Peres-Loschmidt Echo, Dynamical Entropy, Tripartite Mutual Information, and Local-Operator Entanglement. We hence present a unified framework for these existing diagnostics within a single structure. We also go on to quantify how several mechanisms lead to quantum chaos, such as evolution generated from random circuits. Our work paves the way to systematically study many-body dynamical phenomena like Many-Body Localization, measurement-induced phase transitions, and Floquet dynamics.

REFERENCE STYLE

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KEYWORDS

Quantum chaos, process tensor, local operator entanglement, volume entanglement

SIMULATION OF PLASMA DETACHMENT IN TCV USING HERMES-3

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ABSTRACT

Achieving plasma detachment is essential for managing divertor heat loads in magnetic confinement fusion devices. In this work, we investigate detachment physics in configurations relevant to a lower single-null Tokamak à Configuration Variable **(**TCV**)** using the 2D simulations with the HERMES-3 code. By scanning a range of upstream densities, we identify the onset and evolution of detachment within TCV geometry. The model incorporates self-consistent plasma-neutral interactions, including ionization, recombination, and charge-exchange process, enabling detailed analysis of momentum and power balance in the divertor region. Our result captures the characteristic ion flux "rollover", marking the transition from attached to detached regimes characterized by strong volumetric power losses, reduction of target ion flux, and the formation of a cold, dense plasma region near the divertor plates. These results provide insight into the mechanisms governing detachment in TCV configurations and offer guidance for experimental scenarios and future predictive modeling of divertor operation in next-step devices.

This research is supported by the National Research Foundation, Singapore. The computational work for this research was fully performed on resources of the National Supercomputing Centre, Singapore. This research is prepared in part by LLNL under Contract DE-AC52-07NA27344.

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Divertor plasma detachment, *Physics of Plasmas*, 23, 055602, 2016, S. I. Krasheninnikov, A. S. Kukushkin and A. A. Pshenov.

KEYWORDS
Magnetic confinement fusion, plasma detachment, radiation, plasma-neutral interaction, plasma simulation

This study focuses on the research progress of semantic analysis models in physics education, with particular attention to their applications in open-ended response analysis, automated scoring and feedback generation, learning process text analysis, as well as instructional resource and curriculum text analysis. With the development of natural language processing, pretrained language models, and large language models, semantic analysis models have gradually expanded from the automatic classification and scoring of students' answers to the identification of conceptual understanding, types of misconceptions, reasoning processes, and learning support needs. Compared with traditional objective assessment methods, these approaches can reveal students' underlying understanding structures in physics learning in a more fine-grained way, thereby providing support for formative assessment, personalized feedback, and instructional decision-making. At the same time, existing studies still face several challenges, including limited interpretability, unstable scoring reliability, insufficient cross-task generalizability, and the need for better educational applicability. Therefore, this paper aims to systematically review the major application pathways, technological development, educational value, and practical limitations of semantic analysis models in physics education, and to provide a theoretical foundation for the subsequent development of tools for diagnosing conceptual understanding based on open-ended responses.

Comparative study of classical and quantum thermal transport at low temperatures in billiard systems

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ABSTRACT

We explore how quantum mechanics affects low-temperature heat transport in billiard systems at low temperatures. In the classical setting, by considering a simple paradigmatic model, our results reveal the emergence of negative differential thermal resistance: paradoxically, increasing the temperature bias by lowering the cold bath temperature reduces the steady-state heat current. In sharp contrast, the quantum version of the model, described by a Lindblad master equation, shows no such effect—heat current rises monotonically with bias. This marked divergence highlights the fundamental role of quantum effects in low-temperature thermal transport and underscores the need to reconsider classical predictions when designing and optimizing nanoscale thermal devices.

REFERENCE STYLE

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KEYWORDS
Classical thermal transport, Quantum thermal transport, Billiard model, Low temperatures

Configuration distance and double percolation of glassy dissipations

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ABSTRACT

The origin of α and β relaxations in glass-forming liquids remains a fundamental challenge. Here we report a unified picture emerging from extensive molecular dynamics simulations. First, a double-percolation scenario is established: the α process corresponds to percolation of immobile particles, whereas the β relaxation—when well separated—originates from percolation of mobile particles. The ratio of the two percolation temperatures determines whether the β process appears as a distinct peak, a shoulder, or merely a wing. In two dimensions, where simultaneous percolation of both species is impossible, no separate β relaxation exists. Second, a global order parameter, the inherent structure minimal displacement (IS Dmin), is introduced to quantify configurational variability via pattern matching. Across seven model glass formers, the mechanical damping factor (phase angle δ) follows a universal power law with IS Dmin>, reflecting the local curvature of the potential energy landscape. Together, these findings demonstrate that percolation of dynamically distinct regions and landscape-based configurational overlap provide complementary frameworks linking atomic-scale heterogeneity to macroscopic relaxation. This unified perspective offers predictive routes for understanding and designing the mechanical properties of amorphous materials.

KEYWORDS

Glass transition, supercooled liquids, soft matter

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Study of the Effect of Interchange and Adiabaticity in Turbulence Spreading with 2-Fields Fluid Simulations

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ABSTRACT

Turbulence spreading is a fundamental nonlocal process in which fluctuation energy propagates from unstable into weakly unstable or stable regions through nonlinear mode coupling. Its properties depend heavily on the underlying turbulence regime. In particular, drift-wave and interchange turbulence are characterized by different instability drives, mode structures, and transports, all of which can affect the radial propagation of turbulence intensity. In this work, turbulence spreading is investigated using two-dimensional drift-reduced two-field fluid simulations with TOKAM2D. The model evolves the density and vorticity fields and allows systematic variation of the interchange forcing parameter, $\boldsymbol{g}$, and the adiabaticity parameter, $\boldsymbol{C}$. This provides a controlled framework for examining how turbulence spreading changes across regimes ranging from drift-wave-dominated to interchange-dominated dynamics. The study helps clarify the regime dependence of turbulence spreading and offers a reduced-fluid perspective on the mechanisms governing its propagation.

This research is supported by the National Research Foundation (NRF), Singapore. The computational work for this work was fully performed on resources of the National Supercomputing Centre (NSCC), Singapore.

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KEYWORDS

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Tokamak, turbulence spreading, TOKAM2D, drift-wave instability, interchange instability.

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GENERATIVE INITIALIZATION OF GBS SIMULATIONS USING VAE-BASED LATENT FLOW MATCHING

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ABSTRACT

High-fidelity plasma simulations based on the Global Braginskii Solver (GBS) are essential for studying edge plasma dynamics, but they are often computationally expensive, especially when simulations start from random or uniformly prescribed initial conditions. Such initializations may require long transient evolution before reaching physically meaningful plasma states, leading to a considerable waste of computational resources. To address this issue, this work develops a generative reconstruction framework that combines a variational autoencoder (VAE) with latent flow matching for GBS simulation data. The VAE first learns a compact latent representation of high-dimensional plasma fields, while the flow-matching model learns the distributional evolution in the latent space and generates physically plausible plasma states. These generated states are then decoded back to the physical field space and used as simulation initial conditions, replacing conventional random or uniform initialization strategies. By initializing GBS simulations from data-informed generated fields, the proposed approach aims to reduce the initial relaxation stage and accelerate convergence toward statistically meaningful plasma dynamics. Preliminary results show that the VAE-based latent generative model can reconstruct the dominant spatial structures of GBS fields and produce initial states that are more consistent with learned plasma patterns than manually specified initial conditions. This suggests that generative modeling can serve not only as a surrogate reconstruction tool, but also as a practical initialization strategy for accelerating physics-based plasma simulations. The proposed framework provides a promising route toward combining data-driven generative models with first-principles simulation codes for efficient plasma modeling.

REFERENCE STYLE

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StyleGAN as an AI deconvolution operator for large eddy simulations of turbulent plasma equations in BOUT++, *Physics of Plasmas*, 31, 033902, 2024, J. Castagna, F. Schiavello, L. Zanisi, J. Williams.

KEYWORDS
GBS simulation, Plasma modeling, Variational autoencoder, Flow matching, Generative initialization

The FPUT Problem at 70: Do Finite Lattice Systems Ever Thermalize?

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ABSTRACT [*major heading style: Bold 12 pt, UPPERCASE*]
How energy spreads in complex materials is a fundamental question connecting physics, chemistry, and materials science. For decades, theoretical descriptions of energy transfer in nonlinear condensed matter systems have been built on multi-wave exact resonance conditions. However, the actual dynamical role of exact resonances has remained unclear.
Here, we provide direct evidence that exact resonances are *not* the dominant mechanism of energy transport in classical lattices. First, we show that symmetry-induced structures in the kinetic equations cause energy equalization within decoupled mode subsets, dynamically invalidating exact resonance conditions. Second, we demonstrate that exact and quasi-resonances exhibit opposite behaviors with respect to system size: the connectivity of exact resonances decreases monotonically, while that of quasi-resonances increases.
These findings reveal that energy redistribution and eventual thermalization are dominated by quasi-resonances—fleeting interactions enabled by nonlinear frequency broadening. This work establishes a clear distinction between the roles of exact and quasi-resonances in classical lattice dynamics, reshapes our understanding of heat and energy transport in solids, and may inform future strategies for controlling energy transfer in technologies ranging from thermal management to quantum materials. It also implies that thermalization in finite lattice systems requires a threshold in the nonlinear perturbation strength—suggesting that the original FPUT model may never truly thermalize.

KEYWORDS
Quasi-resonances, Thermalization threshold, FPUT problem

Epitaxy of/on 2D Materials: From Interface Engineering to Device Applications

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ABSTRACT
Recent advances in two-dimensional (2D) materials have enabled new device opportunities, yet achieving high performance requires precise control of interfaces and integration. While epitaxy of 2D materials on conventional substrates has been extensively studied, the emerging concept of epitaxy on 2D materials remains less explored. In this talk, I will present our recent advancements in epitaxy on 2D materials, including 2D-2D epitaxy and the growth of epitaxial metal and oxide layers on 2D MoS_2. The resulting high-quality oxides enable integration of high-k dielectrics, leading to MoS_2 top-gate FETs with sub-nanometer equivalent oxide thickness (EOT) and high transconductance. Furthermore, I will discuss the feasibility of remote epitaxy of metals on MoS_2 mediated by ultrathin oxide interlayers, highlighting new pathways for scalable device integration and interface design.

KEYWORDS
2D materials, Transition metal dichalcogenides, MoS_2

Nonlinear optical thermodynamics from a van der Waals-type mean-field theory

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ABSTRACT

Optical thermodynamics offers a distinctive framework for understanding complex phenomena in multimode systems, yet standard ideal-gas-like formulation neglects the effect of nonlinear interaction on thermodynamic quantities, significantly restricting its range of validity. Here, we overcome this limitation by developing a mean-field thermodynamic theory that incorporates the nonlinear renormalization of the mode spectrum. The resulting nonlinear equation of state, analogous to that of the van der Waals for gases, enables the prediction of power-dependent mode localization and the description of optical cooling and heating in photonic Joule-Thomson expansion. Our work establishes a unified thermodynamic perspective on the nonlinear control and transport of optical waves.

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KEYWORDS

Optical thermodynamic, Mean field, Modulation instability, Joule-Thomson expansion

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Laser Wakefield Acceleration and Compact Radiation Sources

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ABSTRACT

Laser wakefield acceleration (LWFA), with an acceleration gradient three orders of magnitude higher than that of conventional radiofrequency accelerators, has become an important research direction in ultrafast and high-intensity laser facilities. After more than two decades of rapid development, the field has gradually transitioned from fundamental studies of LWFA to the development of compact secondary radiation sources driven by such accelerators. In this talk, the research team at SIOM has progressively developed three main research directions based on advancements in electron beam performance: first, the generation of compact free-electron lasers driven by high-quality electron beams; second, the production of intense Betatron radiation X-ray sources using high-charge electron beams; and third, the realization of a laboratory-scale muon source driven by high-energy electron beams. These research directions not only demonstrate the broad application prospects of LWFA in the future but also contribute to advancing the technology toward greater maturity and practical utility.

REFERENCE STYLE

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KEYWORDS

Laser wakefield acceleration, Free-electron lasers, Betatron radiation, Muon source

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Laser Plasma Accelerator and Applications at Peking University

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ABSTRACT [*major heading style: Bold 12 pt, UPPERCASE*]
An abstract not more than **300 words** in length should be typed here. The abstract should provide a concise synthesis of the entire paper, including the purpose of the study, approach, main findings, and interpretation of their significance. The abstract should be a self-contained statement that summarizes the entire paper. Please do not use references and figures in the abstract.
[*leave one blank line between the abstract and "Reference Style"*]

In 2004, laser electron acceleration achieved a milestone breakthrough, and due to its significant importance in high-energy physics and applications, Prof. Mourou and Prof. Strickland were awarded the Nobel Prize in 2018. In the Nobel Prize report, it was mentioned that laser accelerators have the advantage of high electric field gradients, which can accelerate electrons to nearly 10GeV within a distance of~10cm. However, the application of this acceleration technology still faces bottlenecks such as large energy spread, poor stability, and poor repeatability. The beam provided by the laser accelerator has characteristics such as high peak current intensity, short duration (fs~ns), wide energy spread, and controllable single shot dose. In recent years, Peking University has built a laser accelerator device (CLAPA-I), which can provide ~10 MeV/10pC proton beams with energy spread better than 1%, nC level~100 MeV intense electron beams, MeV/u heavy ions, and ultra strong transient gamma rays (8~100 MeV, 10 ^ 9/s). Recently, Peking University had built a CLAPA II accelerator for 100 MeV proton based on PW laser at the Huairou National Science Center. The mouse experiments have confirmed the effectiveness and safety of ultra-high dose-rate laser proton beams (super FLASH), which not only effectively protect normal tissues but also enhance tumor-killing effects, compared to

conventional FLASH radiation therapy. The first human trial is expected to commence next year.

REFERENCE STYLE

Paper Title, *Journal Name*, Volume Number, Page Numbers, Year of Publication, Initial1. LastName1, Initial2. LastName2, Initial3. LastName3, Initial4. LastName4.

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KEYWORDS

ASim 2026, Abstract template, Paper instruction

[*select up to five keywords or brief phrases that best describe the contents of your paper. Each phrase should not contain more than three words. Separate keywords with commas.*]

CPA laser, proton, Ultra high Dose rate, radiation therapy

Hadron Accelerators for Medical Applications

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ABSTRACT

Hadron accelerators are widely used in medical applications. In the hadron therapy field, cyclotrons and synchrotrons are used for producing proton, carbon or multi-ion to treat the cancer tissue. In order to get more higher beam intensity and quicker energy switch time, Full energy linac and laser accelerators are involved for FLASH. In the baron neutron capture field, cyclotrons, RFQ Linac, and tandem provide more than 30 kW proton beam to the target to bombard neutron. In the isotope production, proton cyclotrons no more than 30 MeV are the most used. High energy and power proton Linac, cyclotrons, that can produce alpha-isotope, are more and more studied.

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KEYWORDS

Hadron Accelerator, hadron therapy, Baron neutron capture therapy, isotope production

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The recent process on steady state microbunching EUV light source project

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ABSTRACT

Steady state microbunching (SSMB) proposed by Alexander Chao and Daniel Ratner is a new concept of accelerator light source, which means to maintain the microbunching in storage rings for coherent radiation production. By combining the high coherence and high repetition rate, SSMB can provide very high average power radiation. And the radiation wavelength can cover THz to soft X-ray.

To promote the SSMB physics research and develop a SSMB-EUV light source, a taskforce has been established in Tsinghua University since 2017. Recently, we are continuing the proof of principle experiment and have observed multi-turn coherent radiation by modulating the electron bunch with laser turn-by-turn on MLS storage ring. The experiment results are in very good agreement with theoretical prediction, which proof this kind of mechanism (maintain micro-bunch in storage ring) can work well.

We have also proposed a complete design for high average power EUV radiation based on SSMB. The proposal will provide 350 W EUV average power at the radiation wavelength of 13.5 nm within 2% bandwidth. We have done the start to end study for this proposal and the researches on the key technologies are also underway. This kind of EUV light source may open a new roadmap to meet the requirements of EUV lithography.

KEYWORDS

Steady State Microbunching, accelerator light source

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Construction and Commissioning Progress of the SHINE Accelerator

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ABSTRACT

The Shanghai HIgh repititioN rate XFEL and Extreme light facility (SHINE) is one of the world's most powerful photon sources. Initiated in 2018, this project is designed to build an 8 GeV continuous-wave superconducting linac operating at a repetition rate as high as 1 MHz, with two beamlines delivering photons between 0.2 and 15 keV and six experimental stations in the first stage. Following a step-by-step installation and commissioning approach, major phased milestones are scheduled annually from 2024 to 2027: the 100 MeV injector, 300 MeV linac section, 4 GeV linac with soft X-ray FEL line, and finally the 8 GeV linac with hard X-ray FEL line. This talk will present the progress of SHINE construction and commissioning to date.

REFERENCE STYLE

KEYWORDS

SHINE, Free-Electron Laser, Superconducting RF Linac

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Physics design of the Hefei Advanced Light Facility storage ring

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ABSTRACT

The Hefei Advanced Light Facility (HALF), a soft X-ray diffraction-limited storage ring light source, is currently under construction in Hefei, China, with construction started in 2023 and scheduled for completion in 2028. The HALF storage ring, with a full-energy linac as its injector, consists of 20 identical cells, which employ a modified hybrid six-bend achromat lattice with both long and short straight sections. The natural emittance of the HALF storage ring is 85 pm rad at an energy of 2.2 GeV, with the capability to be increased to 2.5 GeV. The dynamic aperture allows for a nonlinear kicker injection scheme used for user operation. The Touschek lifetime is nearly 8 hours for a 10%-coupling beam. The beam current is 350 mA for Phase I of HALF. HALF will have approximately 35 beamlines in total, the vast majority of which are insertion device beamlines, and 10 of these will be constructed in Phase I.

KEYWORDS

HALF, Storage ring, Physics design

Operational Status and Frontiers in FEL Research at SXFEL

Chao Feng[1,*], Hanghua Xu[1], Bo Liu[1]

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ABSTRACT [*major heading style: Bold 12 pt, UPPERCASE*]
The Shanghai Soft X-ray Free-Electron Laser (SXFEL), China's first X-ray FEL, provides unprecedented capabilities for probing ultrafast dynamics. This presentation reviews its current operational status and recent frontiers in beam physics. SXFEL operates highly efficiently, delivering over 4,500 hours of beamtime annually for user experiments in quantum materials, life sciences, and EUV lithography. We will highlight recent technological breakthroughs, including the milestone demonstration of PWFA XFEL saturation, high-intensity 7-30 THz radiation, and advanced external seeding schemes for fully coherent FELs. Furthermore, developments in attosecond pulses, X-ray vortex beams, and other advanced techniques will be discussed. These continuous upgrades significantly enhance SXFEL's performance, opening new avenues for cutting-edge scientific research.

KEYWORDS
SXFEL, Free-electron laser, Advanced FEL schemes

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Discrete Simulation of Nonlinear Schrödinger Dynamics in a Two Coupled Fiber Loop Temporal Photonic Lattice

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ABSTRACT

The nonlinear Schrödinger equation can describe rich wave phenomena such as soliton formation, modulational instability, and nonlinear localized states. Here we investigate a two coupled fiber loop temporal photonic lattice as a discrete platform for simulating novel nonlinear Schrödinger type propagation, where the effective spatial and evolution dimensions are constructed through time multiplexing and the nonlinear response is introduced through intensity gradient-dependent phase modulation. Theoretical simulations show that, under suitable nonlinear strength and initial conditions, a Gaussian beam can form a stable localized cusp soliton structure and approximately maintain its spatial distribution during propagation. For a flat-top initial beam, the considered topological nonlinearity can preserve the sharp edges of the beam and stabilize localized structures near the boundaries. Our results indicate that the two coupled fiber loop platform can serve as an experimentally realizable system for studying novel discrete nonlinear Schrödinger dynamics, soliton formation, and nonlinear boundary localized states.

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KEYWORDS

Nonlinear Schrödinger equation, Temporal photonic lattice, Soliton formation, Nonlinear localized states，

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Development of Muon Beam Facilities in China

Huan. Jia[1,*], Jingyu. Tang[2], Yu. Bao[3], Kim. Siang Khaw[4], Hanjie. Cai[1], Liangwen. Chen[1], Yuan. He[1], Zhiyu. Sun[1]

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ABSTRACT

With the increasing interest in Muon beam science and applications, more Muon beams are needed around the world. Based on the recent developments of the high power accelerators in China, Muon beam is proposed as one important application in these facilities, like CSNS, SHINE, HIAF and CiADS. With different beam parameters of these facilities, the proposed Muon beam lines have different features and therefore aim for different purpose, like beyond standard model physics, high precision measurement, atomic physics, condensed matter physics, material science and non-destructive element identifications. The energy of Muon beams will cover from meV to GeV level, with the flux from 10^5/s~10^{10} /s. In the talk, the design, key technology development and the future plan of the new Muon beam facilities will be summarized and presented.

KEYWORDS

Muon Beam, Accelerator, Muon Science and Application, New Physics, Condensed matter

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Engineering progress and deployment roadmap of the ADANES Accelerator-Driven Nuclear Energy System

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ABSTRACT

The accelerating global energy transition and stringent dual-carbon targets necessitate a scalable, safe, and sustainable nuclear fission pathway. Accelerator-Driven Systems (ADS) offer a transformative solution by enabling subcritical operation, transmutation of long-lived actinides and fission products, and closed fuel cycles with uranium utilization exceeding 90%. This report presents the engineering progress of the Accelerator-Driven Advanced Nuclear Energy System (ADANES), anchored by the China initiative ADS (CiADS) experimental facility. Key milestones include the commissioning of a high-power superconducting proton linac (600 MeV, 5 mA, beam power >2.5 MW with beam loss control $<10^{-6}$), successful thermal-hydraulic validation of a 3 MW liquid lead-bismuth (Pb-Bi) spallation target, and design completion of a 10 MWt pool-type subcritical reactor. Parallel advancements in high-temperature dry reprocessing (PUMA platform) have demonstrated >95% uranium recovery and efficient separation of semi-volatile/metallic fission products, enabling regenerated fuel pellet fabrication. The CiADS facility is currently advancing through accelerator-target coupling and non-nuclear integral testing, with full-power operation targeted for 2028–2030. The ADANES deployment roadmap outlines a phased progression: a 10 MWt experimental facility (2030), a 100 MWt demonstration plant (2035), and GW-scale industrial units (2040), leveraging a multi-stage breeding–transmutation–burner architecture. With projected generation costs competitive with current PWRs and the elimination of conventional reprocessing surcharges, ADANES positions ADS technology as a technically robust, economically sustainable, and proliferation-resistant cornerstone for next-generation nuclear energy systems and circular fuel management.

KEYWORDS

A scalable, safe, sustainable nuclear fission pathway/ Accelerator-Driven Advanced Nuclear Energy System

Promoting Deep Learning in Physics with the Conceptual Framework Model of Knowledge Integration

Lei Bao

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Deep understanding of core scientific ideas and cross-cutting concepts in STEM has become a central goal of contemporary science education standards. However, extensive research shows that traditional instruction often falls short in helping students develop deep conceptual understanding in physics. To support assessment and instruction that promote knowledge integration and deep learning, we have developed a new Conceptual Framework model, which represents students' knowledge structures with particular attention to the core ideas and sub-dimensions of a given concept. A Conceptual Framework is a content-specific model that maps the knowledge structures of novices and experts, helping to identify missing connections between core conceptual ideas and other elements within the knowledge structure. Assessments based on the Conceptual Framework model emphasize determining which connections exist in students' knowledge structures, while instruction informed by the model targets the development of more expert-like connections. This talk will introduce the Conceptual Framework model and review recent studies demonstrating promising outcomes from its application. Examples of instructional and assessment approaches based on the model will also be discussed.

Promoting Deep Learning in Physics with the Conceptual Framework Model of Knowledge Integration

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Quantum Christoffel nonlinear magnetization

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ABSTRACT
The Christoffel symbol is an essential quantity in Einstein's general theory of relativity. We discover that an electric field can induce a nonlinear magnetization in quantum materials, described by a Christoffel symbol defined in the Hilbert space of quantum states (quantum Christoffel symbol). Through symmetry analysis and first-principles calculations, we identify a number of point groups and 2D material candidates that host this quantum Christoffel nonlinear magnetization. More importantly, this nonlinear magnetization allows the quantum Christoffel symbol to be probed by optical techniques such as magneto-optical Kerr spectroscopy. This quantum Christoffel nonlinear magnetization gives a paradigm of how geometry dictates physics.

REFERENCE
Quantum Christoffel nonlinear magnetization, *Phys. Rev. Lett.* 136, 056302 (2026), Xiao-Bin Qiang, Xiaoxiong Liu, Hai-Zhou Lu*, X. C. Xie.

KEYWORDS
Nonlinear magnetization, Christoffel symbol, Quantum geometry

Manipulating evanescent waves with non-Hermitian spectral singularities

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ABSTRACT

Evanescent waves, characterized by exponential decay along the propagation direction and associated with imaginary wavevector components, play a crucial role in phenomena such as subwavelength imaging and super-Planckian thermal radiation. However, research on wave scattering in non-Hermitian photonics has long focused primarily on propagating waves, and a systematic understanding of evanescent-wave manipulation in non-Hermitian systems remains lacking.

This talk focuses on the role of non-Hermitian spectral singularities in controlling evanescent waves and reveals their synergistic interplay with effective parity–time (PT) symmetry and nonlinear effects. We show that anti-PT-symmetric photonic heterostructures exhibit effective PT-symmetric scattering behavior under evanescent-wave excitation. When the poles of the generalized scattering matrix describing evanescent-wave scattering evolve onto the real-frequency axis, the system supports an evanescent-wave spectral singularity that coalesces with a zero, forming a PT-symmetric laser–absorber mode.

Based on this mode, strong amplification and coherent perfect absorption of evanescent waves can be achieved. Under realistic dispersive conditions, highly tunable near-field energy transport can also be realized. Furthermore, unidirectional spectral singularities can be engineered, enabling strong reflection from one side and vanishing reflection from the other, while maintaining finite and reciprocal transmission. In addition, through the interplay between spectral singularities and nonlinearity, pronounced nonreciprocal transmission of evanescent waves can be achieved without magnetic bias.

These results provide a new perspective on non-Hermitian control of evanescent waves and deepen the understanding of near-field wave dynamics in non-Hermitian systems.

ABSTRACT TOPIC

- Statistical Mechanics and Nonlinear Physics

KEYWORDS

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Evanescent waves, Spectral singularities, Non-Hermitian photonics

THE PHYSICAL MECHANISMS OF BRAIN FUNCTIONS

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ABSTRACT

The human brain is the most complex and mysterious system, performing various important functions of the brain. However, its microscopic mechanism remains a long-standing unsolved problem. In recent years, it has been one of the most important issues in the fields of nonlinear science and complex networks. Based on the progress of complex network science, significant results have been achieved in both brain structural networks and brain functional networks. Particularly in the microscopic mechanism of brain function, the results include chimera states, remote synchronization, remote propagation, and condensation of eigenmodes, etc. This talk will report the preliminary exploration of our group on these issues in recent years, with a focus on discussing the role of complex network science in exploring the microscopic physical mechanism of brain function.

REFERENCE

Physical mechanisms of human brain functions, *Quantitative Biology,* 2025, e70, 2025). Zonghua Liu

KEYWORDS

Brain networks, Brain functions, Chimera state, Remote synchronization, Remote propagation.

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Machine Learning Approach for Heat Conduction in Realistic Materials

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ABSTRACT

First-principles calculations have enabled significant progresses in predicting material's thermal properties without fitting parameters, offering a valuable tool for exploring novel materials. However, challenges remain in modeling complex factors that exists in realistic experiments due to the formidable computational costs. In this talk, I will discuss the advantages of using machine learning approach to study heat conduction in realistic materials and complex systems. A few examples will be demonstrated, including multi-objective prediction, high-order anharmonicity, and structural optimization.

KEYWORDS

Machine learning, heat conduction, high-order anharmonicity, thermal conductivity

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Direct Imaging of Berry Curvature in Spin-compensated Altermagnets and Antiferromagnets

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ABSTRACT

Spin-compensated altermagnets (AM) and antiferromagnets (AFM) offer pathways to spintronic and opto-spintronic devices with minimal stray fields, strong field tolerance, and ultrafast switching. However, detecting and spatially imaging their magnetic order has been challenging, often requiring large-scale facilities. In this talk, I will present our recent results imaging these novel magnetic states—noncollinear AFM Mn_3NiN, noncoplanar AFM $Co_{1/3}TaS_2$, and collinear AM MnTe using a table-top magneto-optic Kerr effect (MOKE) microscope based on a fiber-optic Sagnac interferometer. The observed MOKE signals arise from multiple mechanisms, including momentum-space Berry curvature in systems with strong spin–orbit coupling and real-space Berry curvature in systems without it. This imaging capability enables us to correlate chemical doping with magnetic symmetry and to uncover Berry-curvature density waves.

KEYWORDS

Berry Curvature, MOKE, Altermagnet, Antiferromagnet, Sagnac interferometer

Topological magnons: from material search to experimental realizations.

The discovery of topological insulators not only revealed new topological invariants encoded in many-body quantum mechanics, but also opened a new window into novel material platforms for quantum devices. With the help of ab initio density functional theory for electronic band structures, thousands of new topological electronic materials with protected surface states have been predicted. In contrast, in strongly correlated magnetic materials, density functional theory fails to reliably determine the magnetic interactions, making predictions of topology a challenging task in strongly correlated magnets. Here we present a symmetry-based approach, which predicts topological magnons in a magnetically ordered material, upon applying external perturbations such as magnetic/electric fields and/or mechanical strains. We apply this approach to carry out an efficient semi-automatic search for magnetic materials in the Bilbao Crystallographic Server (BCS). Among 198 compounds with an over 300 K transition temperature, we identify 12 magnetic insulators that support room temperature topological magnons. We further carried out a high throughput automatic search in BCS, and discovered 387 candidate materials for topological magnons, significantly expanding the pool of topological magnon materials. They provide new platforms for potential applications in topological magnon spintronics. We also discuss recent experimental efforts in identifying topological nodal magnons in MnTe2.

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QUANTUM INFORMATION-THERMODYNAMIC COST RELATIONS BEYOND LANDAUER'S PRINCIPLE

Junjie Liu[1,*]

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ABSTRACT

Landauer's principle establishes a fundamental connection between thermodynamic cost and information, serving as a cornerstone at the intersection of thermodynamics and information science. While it has proven successful in a wide range of scenarios, its reliance on assumptions about thermal baths may limit its applicability in generic open nonequilibrium quantum systems, where the environment can be non-thermal and finite-sized. Understanding the intrinsic relationship between information and thermodynamic cost in such systems calls for new theoretical tools. In this talk, we will present our recent theoretical efforts in developing such tools. Our approach builds on a thermodynamic inference strategy that relies solely on system observables, yielding information–thermodynamic cost relations that are agnostic to environmental details and thus broadly applicable. These relations lead to several novel insights, including an upper bound on the heat dissipation of information erasure that complements Landauer's principle, and a generalization of its underlying spirit to constrain higher-order fluctuation costs.

ABSTRACT TOPIC

- Smart grids and energy management systems

KEYWORDS

Nonequilibrium quantum systems, Quantum thermodynamics, Information-cost relation, Thermodynamic inference

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25 years of RHIC journey on nucleon spin structure study

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ABSTRACT

It has been a fundamental question in the field of Quantum Chromodynamics on how the internal partons carry the spin 1/2 of nucleon, in particular after the EMC experiment found only a small fraction of nucleon spin is carried by the quark/anti-quark spin. The world's only polarized proton collider, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, has been providing unique probes to the nucleon spin structure since 2001. Different aspects of the nucleon spin structure have been studied using longitudinally and transversely polarized proton beams with center of mass energies from 62 to 500 GeV and polarizations of about 60%. We will review the highlights on the three pillars of the RHIC spin program over the past 25 years, which cover the gluon and sea quark spin contribution to the nucleon spin, and transverse spin asymmetries in hadronic systems and their implications on parton distribution functions in the collinear and transverse momentum dependent frameworks.

KEYWORDS
RHIC, Nucleon spin structure, Parton distribution functions

Title of the paper

Experimental Signatures and Emerging Evidence of Baryon Junction

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ABSTRACT:
BARYON QUANTUM NUMBER IS BELIEVED TO BE CONSERVED SINCE BARYOGENESIS IN THE EARLY UNIVERSE. WHILE FRACTIONALLY CHARGED VALENCE QUARKS ARE UNDERSTOOD CONVENTIONALLY TO EACH CARRY A BARYON NUMBER OF 1/3, THE BARYON JUNCTION, A NON-PERTURBATIVE Y-SHAPED TOPOLOGY OF NEUTRAL GLUONS, HAS ALSO BEEN PROPOSED AS AN ALTERNATIVE ENTITY TRACING THE BARYON NUMBER. NEITHER SCENARIO HAS BEEN VERIFIED EXPERIMENTALLY. THE STAR COLLABORATION REPORTS MEASUREMENTS AT MID-RAPIDITY OF BARYON NUMBER (B) OVER THE ELECTRIC CHARGE NUMBER DIFFERENCE (DQ) IN ISOBAR NUCLEAR COLLISIONS, AND THE NET-PROTON YIELD ALONG RAPIDITY IN PHOTONUCLEAR COLLISIONS. A LARGER B/DQ RATIO AND LESS ASYMMETRIC NET-PROTON YIELD ARE OBSERVED THAN PREDICTED FROM MODELS ASSIGNING BARYON NUMBER TO VALENCE QUARKS. THESE FINDINGS, CORROBORATED BY PREVIOUS MEASUREMENTS IN AU+AU COLLISIONS, DISFAVOR THE VALENCE QUARK PICTURE. I WILL ALSO PRESENT RECENT MODEL SIMULATIONS, EVIDENCE FROM EARLIER EXPERIMENTS, AND FUTURE PERSPECTIVES FOR IDENTIFYING THE BARYON JUNCTION. TOGETHER, THESE RESULTS OPEN A PROMISING PATH TOWARD RESOLVING THE LONG-STANDING QUESTION OF HOW BARYON NUMBER IS ENCODED IN QCD.

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KEYWORDS
Baryon Number, Relativistic Heavy-Ion Collisions, Nuclear Physics, gluon junction, QCD

Title of the paper

Production and observation of muonic kaon atoms at high-energy colliders

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ABSTRACT

EXOTIC MUONIC ATOMS HAVE LONG PROVIDED PRECISION TESTS OF QED AND NUCLEAR STRUCTURE, YET NO MUONIC SYSTEM CONTAINING A STRANGE QUARK HAD BEEN EXPLORED UNTIL NOW. IN THIS TALK, WE PRESENT A CONCERTED THEORETICAL AND EXPERIMENTAL INVESTIGATION OF MUONIC KAON ATOMS, THE FIRST MUONIC BOUND STATES INVOLVING STRANGENESS. WE DEVELOP A FRAMEWORK FOR $K\MU$ FORMATION IN SEMILEPTONIC D^0 DECAYS USING THE EFFECTIVE WEAK HAMILTONIAN, A HELICITY-BASED TREATMENT OF THE LEPTONIC CURRENT, AND A NONRELATIVISTIC BOUND-STATE PROJECTION, YIELD D^0 TO (Kμ) ATOMS AT A BRANCHING RATIO OF $2.29x10^{-10}$. IN ADDITION TO WEAK-DECAY PRODUCTION, WE EXPAND THE TREATMENT OF QGP-DRIVEN COALESCENCE, IN WHICH THERMAL KAONS AND LOW-MOMENTUM MUONS EMERGING FROM THE EARLY PARTONIC MEDIUM RECOMBINE INTO BOUND STATES AT LATE TIMES. BECAUSE THE QGP PRODUCES COPIOUS STRANGE QUARKS AND A SIGNIFICANT POPULATION OF SOFT MUONS, THIS MECHANISM CAN ENHANCE Kμ ATOM FORMATION WELL BEYOND EXPECTATIONS FROM HADRONIC D^0 DECAYS. OUR MODELING PROVIDES QUANTITATIVE YIELD ESTIMATES AND INDICATES THAT SECONDARY-VERTEX RECONSTRUCTION IN MODERN DETECTORS IS FEASIBLE. A RECENT MEASUREMENT BY THE STAR COLLABORATION AT RHIC DEMONSTRATES THE FORMATION OF STRANGE MUONIC ATOMS AND THEIR ANTIMATTER PARTNERS IN RU+RU AND ZR+ZR COLLISIONS. THESE RESULTS CONSTRAIN THE LEPTON SOURCE SIZE AND EXTRACT PRIMORDIAL LOW-P_T MUONS, SHOWING THAT SYSTEMATIC EXPLORATION OF STRANGE-BEARING MUONIC ATOMS IS NOW ACHIEVABLE.

REFERENCE STYLE

Coalescence formation of muonic atoms at RHIC,
Phys. Lett. B 861, 139242 (2025), arXiv:2410.06518 [hep-ph].
Xiaofeng Wang, Frank Geurts, et al.

Production of muonic kaon atoms at high-energy colliders,
arXiv: 2603.09327,
Xiaofeng Wang, Zebo Tang, et al.

KEYWORDS
QGP, muonic atom, electromagnetic probe, charm meson, form factor

Title of the paper

Production and observation of muonic kaon atoms at high-energy colliders

Xiaofeng Wang[1]

[1]Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

ABSTRACT

EXOTIC MUONIC ATOMS HAVE LONG PROVIDED PRECISION TESTS OF QED AND NUCLEAR STRUCTURE, YET NO MUONIC SYSTEM CONTAINING A STRANGE QUARK HAD BEEN EXPLORED UNTIL NOW. IN THIS TALK, WE PRESENT A CONCERTED THEORETICAL AND EXPERIMENTAL INVESTIGATION OF MUONIC KAON ATOMS, THE FIRST MUONIC BOUND STATES INVOLVING STRANGENESS. WE DEVELOP A FRAMEWORK FOR $K\MU$ FORMATION IN SEMILEPTONIC D^0 DECAYS USING THE EFFECTIVE WEAK HAMILTONIAN, A HELICITY-BASED TREATMENT OF THE LEPTONIC CURRENT, AND A NONRELATIVISTIC BOUND-STATE PROJECTION, YIELD D^0 TO (Kμ) ATOMS AT A BRANCHING RATIO OF $2.29x10^{-10}$. IN ADDITION TO WEAK-DECAY PRODUCTION, WE EXPAND THE TREATMENT OF QGP-DRIVEN COALESCENCE, IN WHICH THERMAL KAONS AND LOW-MOMENTUM MUONS EMERGING FROM THE EARLY PARTONIC MEDIUM RECOMBINE INTO BOUND STATES AT LATE TIMES. BECAUSE THE QGP PRODUCES COPIOUS STRANGE QUARKS AND A SIGNIFICANT POPULATION OF SOFT MUONS, THIS MECHANISM CAN ENHANCE Kμ ATOM FORMATION WELL BEYOND EXPECTATIONS FROM HADRONIC D^0 DECAYS. OUR MODELING PROVIDES QUANTITATIVE YIELD ESTIMATES AND INDICATES THAT SECONDARY-VERTEX RECONSTRUCTION IN MODERN DETECTORS IS FEASIBLE. A RECENT MEASUREMENT BY THE STAR COLLABORATION AT RHIC DEMONSTRATES THE FORMATION OF STRANGE MUONIC ATOMS AND THEIR ANTIMATTER PARTNERS IN RU+RU AND ZR+ZR COLLISIONS. THESE RESULTS CONSTRAIN THE LEPTON SOURCE SIZE AND EXTRACT PRIMORDIAL LOW-P_T MUONS, SHOWING THAT SYSTEMATIC EXPLORATION OF STRANGE-BEARING MUONIC ATOMS IS NOW ACHIEVABLE.

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Coalescence formation of muonic atoms at RHIC,
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Xiaofeng Wang, Frank Geurts, et al.

Production of muonic kaon atoms at high-energy colliders,
arXiv: 2603.09327,
Xiaofeng Wang, Zebo Tang, et al.

KEYWORDS
QGP, muonic atom, electromagnetic probe, charm meson, form factor

Pressure-Energy Equations of State of Hadrons, Superconductor Vortices, and the Cosmos

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ABSTRACT

The pressure–energy equations of state in the nucleon are derived from the gravitational form factors, which parameterize matrix elements of the energy-momentum tensor (EMT), together with EMT conservation. The static pressure distribution arising from the Lorentz trace part of the EMT, as manifested in the spatial stress $\frac{1}{3} T^{ii}$, equals minus the corresponding trace part of the energy density, which can be understood in terms of the gluon and quark condensates. It can be shown that this trace-anomaly- and sigma-term-induced pressure plays a fundamental role in the confinement dynamics of QCD. In contrast, the dynamic pressure distribution from the traceless part of the spatial stress tensor equals $1/d$ of the corresponding traceless part of the energy density, where d is the spatial dimension. We point out that the same pressure–energy relations also hold for vortices in type-II superconductors, where the static pressure–energy relation originates from the Cooper-pair condensate. Furthermore, identical equations of motion appear in the $\Lambda{\rm CDM}$ model of cosmology, where the static pressure–energy relation arises from the cosmological constant.

REFERENCE STYLE

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KEYWORDS

Pressure, energy density, nucleon, superconductors, cosmological constant

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Title of the paper

Probing and Knocking with Muons:
from Muon Colliding to Muon Scattering Experiments, or vice versa

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ABSTRACT

Muon colliders offer a compelling approach to high-energy lepton collisions, enabling multi-TeV center-of-mass energies with minimal synchrotron radiation and strong sensitivity to electroweak and beyond-Standard-Model physics. This talk reviews the physics reach of muon colliders, including precision Higgs measurements and direct searches, together with key challenges in muon production, ionization cooling, rapid acceleration, and mitigation of beam-induced backgrounds from muon decays. These conditions impose stringent requirements on detector timing, granularity, and radiation tolerance. In this context, the PKMu experiment is introduced as a targeted R&D program developing high-resolution muon detectors based on GEM and RPC technologies. Recent results demonstrate their performance and potential contributions to future muon collider detector systems and related applications.

REFERENCE STYLE

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High-Precision Physics Experiments at Huizhou Large-Scale Scientific Facilities, *Chin.Phys.Lett.* 42 (2025) 11, 110102, FengPeng An, et.al.

KEYWORDS

Muon Collider, Muon Beam, Atmosphere Muon, Muon Scattering

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Recent results of PandaX experiment

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[1]School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China.

ABSTRACT

Dark matter remains one of the greatest puzzles in physics and astronomy. Located in China Jinping Underground Laboratory, the PandaX (Particle and Astrophysical Xenon) project consists of a series of dark matter direct detection experiments, aimed to search for dark matter particles and to study fundamental properties of neutrinos. The current experiment, PandaX-4T, employs a dual-phase time projection chamber with a sensitive volume containing 3.7 tonne of liquid xenon. In this talk, I will present latest results of PandaX-4T, and discuss future prospects of PandaX-xT, which will be a multi-ten-tonne liquid xenon, ultra-low background, and general-purpose observatory in China.

KEYWORDS

Dark matter, liquid xenon, time projection chamber, direct detection

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GLOBAL HADRON-HADRON SPIN CORRELATIONS IN RELATIVISTIC HEAVY ION COLLISIONS

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ABSTRACT

Measurements by the STAR Collaboration of global hyperon polarizations and vector meson spin alignments in heavy-ion collisions have confirmed the global polarization of quark matter and indicated strong quark-antiquark spin correlations. Coupled with emerging experimental progress on hadron-hadron spin observables, these developments open new avenues for exploring quark spin correlations and the properties of the quark-gluon plasma (QGP).

We proposed a systematic method to describe quark spin correlations in quark matter, classifying them into local and long-range correlations based on spatial scales. In this framework, the effective quark correlations contain genuine spin correlations originating directly from dynamical processes as well as those induced by averaging other degrees of freedom. To disentangle these correlations, single-hadron polarizations serve as probes for local quark spin correlations (see the companion talk by Zihan Yu for single-hadron polarizations), while hadron-hadron spin correlations are sensitive to long-range quark correlations. This talk focuses on hadron-hadron spin correlations in relativistic heavy-ion collisions, specifically hyperon-hyperon, hyperon-vector meson and vector meson-vector meson systems. We present the key formulas for measurable decay angular distributions to extract these hadron-hadron correlations, discussing how they probe the underlying quark spin correlations within the combination mechanism and their physical consequences in special cases, thereby providing theoretical guidance for future experimental measurements.

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Global Λ hyperon polarization in nuclear collisions: evidence for the most vortical fluid, *Nature*, 548, 62-65, 2017, L. Adamczyk, *et al*.

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Spin alignment of vector mesons in non-central A+A collisions, *Physics Letters B*, 629, 20-26, 2005, Z. T. Liang, X. N. Wang.

* Corresponding author email: jipenglv@mail.sdu.edu.cn

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A systematic study of global spin polarizations and correlations of hadrons with different spins in relativistic heavy ion collisions, *arXiv:2603.15135*, 2026, J. P. Lv, Z. H. Yu, X. W. Li, Z. T. Liang.

KEYWORDS

Quark spin correlations, Heavy-ion collisions, Global polarization, Hadron-hadron observables, Quark matter

Highlights of BESIII Experiment

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[1]School of Physics, Sun Yat-sen University, China.

ABSTRACT

The BESIII experiment is located at BEPCII, a symmetric e+e- collider operating at c.m. energy from 2.0 to 4.95 GeV. With the world's largest on-threshold production dataset of J/ψ, ψ(3686), ψ((3770) and data collected at other energy points, we are able to study various physics topics, including light hadrons, charmonium, charm hadrons, tau physics, QCD and new physics beyond the standard model. In this presentation, we highlight the discoveries of new resonances at BESIII, precise measurements of CKM matrix elements |Vcs|, |Vcd| and test of lepton flavor universality, test of quantum entanglement, search for the source of CP violation, search for dark matter and new physics beyond the standard model.

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Probing CP symmetry and weak phases with entangled double-strange baryons, *Nature*, 606, 64, 2022, M. Ablikim, BESIII Collaboration.

KEYWORDS

BESIII, Charm, New physics

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GLOBAL HADRON SPIN POLARIZATION

IN RELATIVISTIC HEAVY ION COLLISIONS

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[1]Institute of Frontier and Interdisciplinary Science, Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, China.

ABSTRACT

The STAR Collaboration results on global polarization of hyperon in heavy-ion collisions have confirmed the global polarization of the quark-gluon plasma (QGP). Then the result on spin alignment of vector mesons, together with the hyperon polarization, revealed that quarks in QGP exhibit not only global polarization but also spin correlations, leading the study on spin effects in heavy-ion collisions to a new climax.

We proposed a systematic formalism for describing spin correlations in a system of spin-1/2 particles such as QGP, where the quark spin correlation can be divided into local correlations inside a single hadron, which can be probed by the tensor polarization of spin-1 and spin-3/2 hadrons, and long range correlations between two hadrons, which can be studied by hadron-hadron spin correlations. This report aims to present the polarizations of hadrons of various spins and their relationship to local quark spin correlations in a multi-quark system.(For long range quark spin correlations and hadron-hadron correlations see Ji-peng Lyu's talk.) We show that the polarization of spin-1/2 baryons is mainly determined by quark polarizations and the spin alignment of vector mesons is dominated by quark-anti quark spin correlations, while the rank-2 and rank-3 tensor polarizations of spin-3/2 baryons reflect local two-quark and three-quark spin correlations respectively. We also show methods for extracting these correlations from measurements of baryon decays, and measurements of such polarization properties for the first time provide an opportunity to study local quark(anti quark) spin correlations in relativistic heavy ion collisions.

REFERENCE

Global Λ hyperon polarization in nuclear collisions: evidence for the most vortical fluid, *Nature*, 548, 62–65, 2017, L. Adamczyk, *et al*.

Pattern of global spin alignment of ϕ and K^{*0} mesons in heavy-ion collisions, *Nature*, 614, 244-248, 2023, M. S. Abdallah, *et al.*

Globally polarized quark-gluon plasma in non-central A+A collisions, *Physical Review Letters*, 94, 102301-1–102301-4, 2005, Z. T. Liang, X. N. Wang.

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Spin alignment of vector mesons in non-central A+A collisions, *Physics Letters B*, 629, 20-26, 2005, Z. T. Liang, X. N. Wang.
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KEYWORDS
Quark spin correlation, Global tensor polarization, Heavy-ion collision, Quark-gluon plasma

RECENT RESULTS FROM THE BELLE II EXPERIMENT

M.-Z Wang[1,*]
on behalf of the Belle II Collaboration

[1]Department of Physics, National Taiwan University, Taiwan, R.O.C.

ABSTRACT
The Belle II experiment at the SuperKEKB energy-asymmetric $e^+ e^-$ collider is a substantial upgrade of the B factory facility at the Japanese KEK laboratory. Recent results obtained from Run 1, consisting of 426 fb$^-1$ of data collected between 2019 and 2022 at center-of-mass energies near the mass of the Upsilon(4S), will be shown. The physics topics are related to B decays, D decays, τ decays and new physics searches.

REFERENCE
https://www.belle2.org/research/physics/publications

KEYWORDS
Belle II, B decays, D decays, τ decays, new physics searches

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CP VIOLATION IN HEAVY BARYON DECAYS

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Institute of Physics, Academia Sinica, Taipei, Taiwan, Republic of China.

ABSTRACT

I review recent theoretical progress on heavy flavor physics, focusing on CP violation in heavy baryon decays. This talk is motivated by the first observation of the direct CP asymmetry in the Lambda_b baryon decay into the multi-particle final state p pi pi K at the LHCb [Nature 643 (2025) 8074, 1223-1228]. I summarize the theoretical efforts of exploring the involved dynamics, the difference between heavy baryon and meson decays in terms of partial-wave CP violation, why it is more difficult to measure CP asymmetries in the former than in the latter, and what strategy led to the prediction for the CP asymmetry in the Lambda_b to p pi pi K mode that was confirmed by experimental data later.

REFERENCE STYLE

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KEYWORDS

CP violation, Heavy baryon decays, Partial waves

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Project status and perspective of the Super Tau Charm Facility

Jingyu Tang for the STCF team
School of Nuclear Science and Technology, University of Science and Technology of China, Huangshan Road 443, Hefei 230027, China

The Super Tau-Charm Facility (STCF) was proposed as a third-generation circular electron-positron collider in the energy range of 2-7 GeV (CoM) and with a luminosity greater than 5*10^34 cm^-2s^-1 @4 GeV, aiming to explore charm physics and tau physics in the next decades. This seminar will introduce the science goals, facility design, R&D efforts and project planning of STCF, but with the main focus on the accelerator. Under the financial support of the key technology R&D project by the local governments and other national funding agencies, the STCF accelerator team including international collaborators has completed the conceptual design of the accelerator in 2024, and is working on the technical design. The accelerator consists of a full-energy injector consisting of multi-section linacs and a positron damping/accumulator ring and a double-ring collider with the crab-waist collision scheme. Key accelerator physics and technological challenges will be addressed. Ongoing R&D efforts and progresses will be summarized. The baseline design has one detector, but the reserved space for the second detector is also reserved. The project planning will also be given.

LATEST RESULTS ON HIGGS PHYSICS

Pai-hsien Jennifer Hsu[1]

[1]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan.

ABSTRACT
In this talk I will present highlights on recent Higgs physics results from the ATLAS and CMS experiments, including Higgs couplings and self-couplings, properties of the Higgs boson, rare decay modes, and probing new physics with the Higgs boson measurements.

KEYWORDS
LHC, ATLAS, CMS, Higgs boson

When Does a Dark Matter Halo Collapse?

ABSTRACT [*major heading style: Bold 12 pt, UPPERCASE*]

Although the existence of dark matter is well established, its nature remains elusive. Dark matter could be part of the "dark sectors," comprising hidden particles with new interactions. Such interactions could cause dark matter to self-interact, altering the formation and evolution of dark matter halos. Self-interacting dark matter halo undergoes gravothermal evolution, where the central halo first forms a core that ultimately collapses. The resulting cored and collapsed phases diversify the density profiles of dark matter halos. In particular, the ultra-dense substructures produced in the collapsed phase can be effectively probed by gravitational lensing observations. Furthermore, collapsed halos may seed the high-redshift supermassive black holes, addressing an emerging puzzle in astrophysics.

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Direct Measurement of Neutrino Mass Based on Low-Decay-Energy Nuclides and Superconducting Detection Technology

Ying Fu[1], Yu Liu[1], Wenjiang Yang[1], Yizheng Wang[1], Yifei Zhang[1], Zhengwei Li[1], Xilei Sun[1], Xiaoyu Yang[1], Huaqiao Zhang[1], Yuekun Heng[1,2,3*]

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[2] State Key Laboratory of Particle Detection and Electronics, Beijing 100049, China

[3] University of Chinese Academy of Sciences, Beijing 100049, China

ABSTRACT

The measurement of neutrino mass is a long-standing major scientific challenge with profound significance for both particle physics and astrophysics. The energy spectra of β-decay or electron capture (EC) in radioactive nuclides can be utilized to directly determine the neutrino mass. Isotopes with low decay energy exhibit particular advantages for improving the sensitivity of neutrino mass measurements, owing to the significantly enhanced decay rate near the endpoint region of the decay energy spectrum. This work includes the production of low-background, low-decay-energy artificial isotopes using a proton accelerator, the research of superconducting detectors with high energy resolution and fast time response, and the precise measurement of the decay energy spectra of electron capture in the isotopes. We expect to achieve a direct measurement of the electron neutrino mass with 0.05 eV sensitivity at the 90% confidence level.

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[3] High-resolution and low-background spectrum: interpretation of the resonance tails *Eur Phys J C*, 79 (2019), p. 1026, C. Velte, F. Ahrens, A. Barth, et al.

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KEYWORDS
Neutrino Mass; Direct Measurement; Electron Capture; Isotope; Superconducting Detector

Title of the paper

[*Ultralight Particle Hunts Using Gravitational-Wave Interferometers and Black Hole Polarimetry*]

Yue Zhao

[1]Hong Kong University of Science and Technology, Hong Kong, China

ABSTRACT

Ultralight particles, such as axions and dark photons, arise naturally from the compactification of extra dimensions. This talk presents new detection strategies to search for these candidates. First, I will show how LIGO–Virgo–KAGRA gravitational-wave detectors serve as multi-purpose direct-detection observatories for ultralight dark matter. Direct searches for various possible candidates—including dark photons, axions, and dilatons—have been performed and previously unexplored parameter space has been covered. Second, I will discuss how the Event Horizon Telescope's angular resolution enables tests of axion clouds around a supermassive black hole, like M87*. By analyzing the azimuthal distribution of linear polarization, we derive the strongest constraints on the axion–photon coupling in a certain mass window. Together, these results demonstrate that gravitational-wave interferometers and black-hole polarimetry have become powerful laboratories for ultralight particle detection.

REFERENCE STYLE

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Phys.Rev.Lett. 121 (2018) 6, 061102

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LIGO-Virgo-KAGRA Collaboration
Phys.Rev.D 105 (2022) 6, 063030

Direct multi-model dark-matter search with gravitational-wave interferometers using data from the first part of the fourth LIGO-Virgo-KAGRA observing run
LIGO-Virgo-KAGRA Collaboration
e-Print: 2510.27022 [astro-ph.CO]

Probing Axions with Event Horizon Telescope Polarimetric Measurements
Yifan Chen, Jing Shu, Xiao Xue, Qiang Yuan, Yue Zhao
Phys.Rev.Lett. 124 (2020) 6, 06110

Stringent constraints on axion-photon coupling with Event Horizon Telescope polarimetric measurements of supermassive black hole M87⋆
Y. Chen, Y. Liu, R. Lu, Y. Mizuno, J. Shu, X. Xue, Q. Yuan, Y. Zhao
Nature Astron. 6 (2022) 5, 592-598

KEYWORDS
ASim 2026, Abstract template, Paper instruction
[*new physics, dark matter, gravitational wave, EHT*]

Status of the CEPC

Miao He[1,*]

[1]Institute of High Energy Physics, Beijing, China.

ABSTRACT

The Circular Electron Positron Collider (CEPC), proposed by the Chinese High Energy community in 2012, is designed to run at a center-of-mass energy of 240 GeV as a Higgs factory. The CEPC can also be operated at lower energies to deliver an unprecedented amount of Z and W bosons, and further be upgraded to run at higher energy to the top pair threshold. The CEPC Conceptual Design Report (CDR) was formally released in November 2018. Subsequently, the Technical Design Report (TDR) for the CEPC accelerator was published on December 25, 2023, followed by the reference detector TDR on October 6, 2025. The CEPC team is now advancing key technology development and validation efforts, with the goal of delivering an Engineering Design Report. In this talk, we will briefly review the CEPC's physics potential and focus on the current status of R&D activities for both the accelerator and the detector.

REFERENCE

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[2] CEPC Technical Design Report: Reference Detector, arXiv:2510.05260, The CEPC Study Group

KEYWORDS

CEPC, Higgs, Accelerator, Detector

* Corresponding author email: hem@ihep.ac.cn

Probing QCD matter from spin transport in nuclear collisions

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[2] Physics Division, National Center for Theoretical Sciences, Taipei, 106319, Taiwan.

ABSTRACT

In relativistic heavy-ion collisions, the collective behaviors of deconfined quarks and gluons characterized by the hadron spectra and anisotropic flow reveal the formation of quark gluon plasma (QGP), which can be macroscopically described by relativistic hydrodynamics with the transport coefficients governed by the underlying strong interaction. Recent measurements of the global spin polarization of Lambda hyperons further indicate the presence of strong vorticity of the rotating QGP and manifest the relativistic Barnett effect at the subatomic scale. However, it is elusive how we could further explore the microscopic properties of a QCD medium through spin-related observables. Recently, the measured spin alignment phenomena of vector mesons cannot be simply explained by the vorticity, which may lead to such a new opportunity. Microscopically, a considerable number of soft gluons, in the QGP phase or even in the glasma phase as its precursor with overpopulated gluons in the color-glass-condensate effective theory, may be delineated by fluctuating chromo-electromagnetic fields (or color fields for short). We will discuss how such color fields may potentially result in the spin alignment through the anisotropic spin correlation of the quark and antiquark forming a vector meson via quark coalescence. Also, the pertinent effects from color-field correlators with anisotropic quark flow could give rise to local spin polarization of Lambda hyperons along the beam direction. We may employ the spin transport phenomena to probe the microscopic interaction of QCD matter in high-energy nuclear collisions.

REFERENCE STYLE

KEYWORDS

Relativistic heavy-ion collisions, quark gluon plasma, quantum field theory, quantum chromodynamics, quantum kinetic theory

Title of the paper

Hunting the Unusual: AI and Exotic Signatures Beyond the Standard Model

S.-C. Hsu

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ABSTRACT

The Standard Model (SM) is remarkably successful yet incomplete, inspiring a rich landscape of theories for physics beyond the SM (BSM), including supersymmetry, hidden or dark sectors, and extended Higgs or gauge sectors predicting heavy resonances and long-lived states. These scenarios often produce unusual collider signatures that evade traditional prompt-object searches. This talk, "Hunting the Unusual: AI and Exotic Signatures Beyond the Standard Model," will present recent LHC results that probe a broad range of such phenomena, from high-mass resonances in dijet and multilepton final states to unconventional topologies with striking spatial and temporal structures. Particular emphasis will be placed on long-lived particles producing displaced vertices and displaced leptons, as well as dark-sector–motivated emerging jets in which hadronic activity gradually develops from displaced, low-multiplicity seeds. Complementing these targeted analyses, we are developing and deploying real-time AI strategies at the trigger level to identify anomalous events with these exotic signatures, enhancing the LHC's ability to capture unanticipated BSM phenomena in current and future running.

REFERENCE STYLE

Missing-mass search in forward-proton-tagged dilepton events with the ATLAS detector, arXiv:2603.01991 (2026), ATLAS Collaboration.

Search for massive, long-lived particles in events with displaced vertices and displaced muons in pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS experiment, arXiv:2510.12347 (2025), ATLAS Collaboration

Strategy and performance of the CMS long-lived particle trigger program in proton – proton collisions at $\sqrt{s} = 13.6$ TeV, arXiv:2601.17544, CMS Collaboration

Search for dark QCD with emerging jets in proton – proton collisions at $\sqrt{s} = 13$ TeV, *JHEP 07 (2024) 142*, CMS Collaboration

KEYWORDS

Beyond Standard Model, long-lived particles, displaced signatures, emerging jets, real-time AI

Experimental Studies of Chiral Magnetic Effect and Magnetic Field in Heavy Ion Collisions

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Quantum ChromoDynamics (QCD) which governs the interactions of quarks and gluons allows for collective gluonic excitations with finite topological charges due to the non-Abelian nature of the quantum field theory. Transitions between these excitation states could lead to the formation of chirality unbalanced domains where the numbers of right handed and left-handed quarks are unequal. The chirality of these quarks, under the influence of the strong magnetic field generated by spectator protons moving at nearly the speed of light, could produce an electric current along the magnetic field direction. This Chiral Magnetic Effect (CME) could result in charge separation signals along the magnetic field direction in the final state charged particles. The presence of the CME violates the Parity symmetry locally in the strong interactions, and could represent intrinsic properties of the QCD theory. The search for the CME in heavy ion collisions has been a major scientific objective at RHIC. I will review the status of experimental studies of the CME and the magnetic field in heavy ion collisions at RHIC with the STAR experiment.

KOTO and KOTO-II: Search for New Physics through the $K_L \to \pi^0 \nu\bar{\nu}$ decay

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ABSTRACT

The rare decay $K_L \to \pi^0 \nu\bar{\nu}$ is considered a "golden channel" in particle physics, providing one of the cleanest probes for New Physics due to its theoretical precision and rareness in the Standard Model (SM). KOTO is the dedicated experiment searching for this decay and has recently set the world-leading upper limit on its branching ratio at 2.2×10^{-9} (90% confidence level) using data collected in 2021. While significant, this limit remains two orders of magnitude above the SM prediction. To precisely measure this decay and examine the SM, the KOTO-II experiment has been proposed as a major upgrade. By utilizing a harder K_L momentum spectrum, increased K_L flux, and an optimized detector design, KOTO-II aims to either confirm SM predictions or uncover clear evidence of New Physics. The KOTO-II collaboration, consisting of 87 members from 11 countries, aims to begin the experiment in the 2030s. This presentation will cover the current status and future prospects of the project.

REFERENCE STYLE

Search for the $K_L \to \pi^0 \nu\bar{\nu}$ Decay at the J-PARC KOTO Experiment, *Physical Review Letters*, 134, 081802, 2025, J. K. Ahn et al.

KEYWORDS

Kaons, CP violation, Rare decays, Flavor changing neutral currents

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A Proposal for a Quantum Mechanical Model of Black Hole

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ABSTRACT

Black holes pose sharp consistency questions at the interface of gravity, quantum mechanics, and thermodynamics. It is widely believed that resolving problems such as providing a microscopic account of Bekenstein–Hawking entropy, understanding the origin of black hole thermodynamics, and resolving the information paradox posed by Hawking radiation will provide valuable insights to the construction of the theory of quantum gravity.

In this talk, I discuss a recent proposal [1,2] of a quantum mechanics of quantized space as a model of quantum black hole and quantum gravity in 4-dimensions. Our construction was motivated by the bottom-up approach [3,4]. As a system of quantum bits of quantum space, our model reproduces not only the needed macroscopic properties of the Schwarzschild black hole [1] and the rotating Kerr black hole [2], it also provides a microscopic counting of the Bekenstein-Hawking entropy of black hole [1,2] and explains the origin of Hawking radiation in terms of a tunneling process of emission of monopole in the quantum mechanics [5].

As application, I discuss how the well-known membrane paradigm of black hole is modified by quantum gravity effects [6]. In classical general relativity, the black hole membrane is an electrical conductor with a constant vacuum resistivity. We identify new quantum gravity effects and show that the quantum black hole membrane has also a frequency dependent inductance and a chiral Hall conductance. We propose to test these new effects with the observation of quasi-normal modes.

1. Matrix model proposal for quantum gravity and the quantum mechanics of black holes, Phys.Rev.D 112 (2025) 6, 066001, Chong-Sun Chu
2. Quantum Kerr black hole from matrix theory of quantum gravity, Phys.Rev.D 112 (2025) 4, 046014, Chong-Sun Chu
3. Fermi model of a quantum black hole, Phys.Rev.D 110 (2024) 4, 046001, Chong-Sun Chu
4. Tunneling of Bell particles, page curve and black hole information, Phys.Lett.B 865 (2025) 139486, Chong-Sun Chu
5. Hawking Radiation from Tunneling in Black Hole Quantum Mechanics, e-Print: 2603.12199 [hep-th], Chong-Sun Chu
6. Membrane Paradigm for Quantum Black Hole, *to appear,* Chong-Sun Chu

KEYWORDS
Quantum gravity, Quantum black hole, Information paradox, Membrane paradigm, Quasi-normal modes.

Extraction of transverse-momentum dependent helicity distribution functions

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ABSTRACT

Three-dimensional imaging of the nucleon spin structure provides essential insight into nonperturbative QCD dynamics. Building on our previous extraction of transverse-momentum-dependent helicity distributions from SIDIS longitudinal double-spin asymmetries within TMD factorization[1], this work revisits the interpretation of existing experimental data and refines the treatment of the corresponding χ^2 analysis. Based on the extracted helicity TMD distributions, we investigate the transverse-momentum dependence of parton polarization and its connection to spin-dependent nucleon tomography. Predictions for the $\cos\phi_h$ azimuthal modulation are presented and compared with available measurements as an independent phenomenological check of the TMD framework. We further perform projection studies for the future electron-ion collider in China, incorporating its expected high luminosity, polarized beams, and broad kinematic coverage. The projected measurements demonstrate strong potential to improve the determination of helicity TMD distributions and related azimuthal observables, particularly in the sea-quark and low-x regions. These studies show that spin-dependent observables at EicC can provide important information on the three-dimensional spin structure of the nucleon and the underlying nonperturbative mechanisms of QCD.

REFERENCE STYLE

[1] First Extraction of Transverse-Momentum Dependent Helicity Distributions, *Physical Review Letters*, 134, 121902, 2025, **K. Yang**, T. Liu, P. Sun, Y. Zhao, B.-Q. Ma

KEYWORDS

Spin structure, Three-dimensional nucleon structure, Transverse momentum dependent helicity distribution function, azimuthal spin asymetry

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Classical analog of the T. D. Lee model for renormalization

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ABSTRACT

Although divergence and renormalization of physical quantities are frequently encountered in quantum field theory (QFT), they are not necessarily quantum-specific characteristics. We show in this paper that there exists a classical counterpart of the Lee model which is the model of coupled harmonic oscillators (CHO). It is demonstrated that the frequency divergence in this classical model precisely replicates the phenomenon of mass divergence in the Lee model, as does the corresponding renormalization procedure. Considering the arbitrariness in renormalization schemes, we establish necessary conditions that a general renormalization must satisfy for the model of two coupled oscillators which corresponds to the single-mode Lee model. Furthermore, we analyze the classical analog of the N-θ scattering process and show that the dependence of scattering strength on the cutoff mode mirrors that of the quantum case. These findings challenge the quantum-centric view of mass renormalization in the Lee model and offer new insights into the classical-quantum correspondence in renormalization theories.

REFERENCE STYLE

Classical analog of the T. D. Lee model for renormalization, *Nuclear Physics, Section B*, 1022, 117228, 2026, K. Xu, C.P. Sun.

KEYWORDS

Lee model, renormalization, Quantum-classical correspondence.

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QED CORRECTIONS TO HIGH-TRANSVERSE-MOMENTUM HADRON PRODUCTION IN DEEP-INELASTIC SCATTERING

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ABSTRACT

Semi-inclusive deep-inelastic scattering (SIDIS) is high-energy lepton-nucleon scattering with a produced hadron measured in the final state. It is a central tool for probing hadron structure and testing quantum chromodynamics (QCD). Persistent discrepancies between theory and data have been observed in SIDIS at large transverse momentum, where quantum electrodynamics (QED) corrections remain poorly studied. The purpose of this work is therefore to determine how QED corrections modify SIDIS observables in this regime.

To address this question, we carry out a systematic analysis in a hybrid factorization framework, incorporating QED corrections within collinear QED factorization and describing the hadronic subprocess with transverse-momentum-dependent (TMD) and collinear QCD factorization in their respective kinematic regions. We evaluate the resulting corrections to SIDIS hadron multiplicities for COMPASS and Electron-Ion Collider kinematics.

Our analysis shows that QED corrections can have a substantial numerical impact in the large-transverse-momentum region, in some cases changing predicted multiplicities by up to an order of magnitude. This sizable effect can help reduce, though not fully resolve, tensions between theory and existing SIDIS data. More importantly, we identify a kinematic mechanism by which QED corrections shift the underlying hard-scattering configuration so that the true hadron transverse momentum can become small even when the observed transverse momentum is large. As a result, nonperturbative TMD dynamics and uncertainties from the TMD-to-collinear matching region can contaminate observables that are usually assumed to be governed purely by perturbative large-transverse-momentum dynamics.

These results demonstrate that QED corrections are not a minor effect but an essential ingredient of a consistent factorized description of SIDIS. The study has important implications for precision QCD analyses and for the interpretation of future measurements at facilities such as the Electron-Ion Collider.

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KEYWORDS

SIDIS, QED corrections, Transverse momentum, Factorization

Latest Results on Electroweak Physics at LHC

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ABSTRACT

This talk will give an overview of recent LHC Electroweak physics results from ATLAS, CMS and LHCb experiments including the highlights of recent W/Z mass and Weak Mixing Angle precision measurements, inclusive di-boson precision measurements, Vector Boson Scattering (VBS) polarization measurements, tri-boson measurements and observations, etc. With the presented results, the talk will also emphasize the important and deep connection between Electroweak Symmetry Breaking (EWSB) and Higgs mechanism, particularly on the VBS longitudinal polarization and Higgs unitarization interplaying the EWSB and Nambu-Goldstone nature of weak bosons, the tri-boson productions and Higgs production with di-boson decays in association with a vector boson. The related BSM probes via anomalous gauge couplings with EFT interpretations will also be presented and discussed.

REFERENCE STYLE

Evidence of ZZγ production with the ATLAS detector, arXiv:2602.17165, ATLAS Collaboration

Observation of $W^+W^-\gamma$ production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector and constraints on anomalous quartic gauge-boson couplings, Phys. Lett. B 873 (2026) 140050, ATLAS Collaboration

Measurements of $ZZ\to\ell\ell\nu\nu$ and $ZZjj\to\ell\ell\nu\nu jj$ productions in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, arXiv:2511.15569, ATLAS Collaboration

Evidence for longitudinally polarized W bosons in the electroweak production of same-sign W boson pairs in association with two jets in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Phys. Rev. Lett. 135 (2025) 111802, ATLAS Collaboration

Observation of double parton scattering in same-sign W boson pair production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Phys. Lett. B 870 (2025) 139892, ATLAS Collaboration

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Measurements of differential cross sections and search for neutral triple gauge couplings in pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2025-001, ATLAS Collaboration
Evidence of ZZγ production and observation of 4ℓγ in proton-proton collisions at √s = 13 TeV, arXiv:2604.02594, CMS Collaboration
Measurement of Zγ production in proton-proton collisions at √s = 13.6 TeV and constraints on neutral triple gauge couplings, arXiv:2512.08582, CMS Collaboration
Measurement of the $Z \to \mu^+\mu^-$ angular coefficients in pp collisions at √s = 13 TeV as functions of transverse momentum and rapidity, arXiv:2604.25678, CMS Collaboration
Measurement and effective field theory interpretation of the photon-fusion production cross section of a pair of W bosons in proton-proton collisions at √s = 13 TeV, arXiv:2601.21574, CMS Collaboration
Measurement of the Z-boson mass, Phys. Rev. Lett. 135 (2025) 161802, LHCb Collaboration
Measurement of the effective leptonic weak mixing angle, JHEP 12 (2024) 026, LHCb Collaboration

KEYWORDS
LHC, Electroweak, Multi-Boson, VBS, Precision Measurements

New Physics Searches from EFT Precision to Future Colliders

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ABSTRACT

The null result of the LHC searches indicates new physics might be beyond the LHC threshold, leading to a paradigm shift from model building to effective field theory (EFT). I will discuss the operator construction of the SMEFT operators, and LHC status of effective operators at the dim-6 and beyond, and motivate why UV resonances are still needed in the EFT framework. We propose a bottom-up strategy of searching such UV resonances, which contains only 47 resonances at the leading order, comparing infinitely many UV resonances in traditional searches of new physics.

REFERENCE STYLE

Complete tree-level dictionary between simplified BSM models and SMEFT Operators,, *Phys.Rev.D 109 (2024) 9, 095041,* X. X. Li, Z. Ren, J-H, Yu

The bottom-up EFT: complete UV resonances of the SMEFT operators, *Journal of High Energy Physics*, 11, 170, 2022, H. L. Li, Y.-H. Ni, M.-L. Xiao, J.-H. Yu.

KEYWORDS

EFT,SMEFT, New Physics, TeV resonances, LHC

Mechanical Phonon-Assisted Free-Electron–Photon Scattering in an Optomechanical Cavity

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ABSTRACT

Free electrons provide coherent and ultrafast probes of light–matter interaction, enabling electron-beam shaping, photonic state control, quantum sensing, and free-electron quantum optics. However, direct inelastic photon absorption and emission by free electrons in spatially extended optical fields are strongly constrained by energy–momentum conservation, leading to negligible coupling in free space or conventional cavity modes. Existing strong-coupling platforms therefore often rely on highly localized near fields, as in photon-induced near-field electron microscopy, but this requirement limits the range of accessible geometries and physical scenarios.

Here, we show that an optomechanical cavity with a vibrating mirror can open a new route to strong coherent free-electron–light interaction. Starting from a relativistic Hamiltonian for a free electron coupled to a cavity field and a mechanical phonon mode, we derive an effective scattering operator and evaluate the corresponding coupling strength. We find that the mechanical vibration is not a passive background degree of freedom: through radiation pressure, a single collective vibration mode of the mirror enters the microscopic electron–photon scattering pathway and forms hybrid electron–photon–phonon channels. In these channels, photon absorption or emission by the free electron is accompanied by an optomechanical Kerr energy shift, which compensates the energy mismatch that suppresses the direct inelastic process.

By engineering the optomechanical response, the hybrid scattering channel can be shifted into a phase-matched regime, producing a strong enhancement of the effective electron–photon coupling without requiring highly localized optical near fields. Our results identify optomechanical cavities as a promising platform for mechanically assisted coherent free-electron–light interactions and reveal how mechanical motion of a cavity element can actively reshape microscopic free-electron quantum scattering.

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KEYWORDS
Free electron dynamics, Cavity-QED, Light-matter interaction, Cavity Optomechanics, Nonlinear optics

LATEST RESULTS IN GRAVITATIONAL-WAVE PHYSICS: FROM STRONG-FIELD GRAVITY TO COSMOLOGICAL SIGNALS

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ABSTRACT
The LIGO-Virgo-KAGRA network and Pulsar Timing Arrays have recently produced results with significant implications for fundamental physics. The O4 observing run of the LIGO-Virgo-KAGRA network has expanded the catalog of compact binary mergers, enabling precision tests of general relativity in the strong-field regime. These observations place competitive constraints on the graviton mass and gravitational-wave propagation speed. Meanwhile, the nanohertz stochastic background detected by NANOGrav and global Pulsar Timing Arrays collaborations may carry signatures of cosmological phase transitions or cosmic string networks scenarios. We summarize the current landscape of results and discuss how next-generation detectors such as Einstein Telescope and LISA will sharpen these fundamental physics tests in the coming decade.

REFERENCE STYLE
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KEYWORDS
Gravitational waves, compact binary mergers, stochastic background, strong-field gravity, cosmology

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SLEGS AT SSRF AND FUTURE LCS SOURCES: ENERGY-TUNABLE GAMMA-RAY FACILITIES FOR PHOTONUCLEAR PHYSICS AND EMERGING USER OPPORTUNITIES

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ABSTRACT

The Shanghai Laser Electron Gamma Source (SLEGS) at SSRF is a cutting-edge laser Compton scattering (LCS) gamma-ray facility dedicated to photonuclear physics research. Commissioned in 2022 and open to users since 2023, it uses 10.64 μm photons from a 100 W CO_2 laser and 3.5 GeV electrons circulating in the SSRF storage ring to generate quasi-monochromatic, continuously energy-tunable gamma-rays from 0.25 to 21.7 MeV by varying the scattering angle from 20° to 160°. SLEGS is able to deliver a flux of ~10^7 photons/s with 5%–15% energy resolution [1]. It is the world's first versatile slant-scattering LCS beamline, offering unique energy scanning capability without changing the electron beam energy, which is highly attractive for systematic nuclear physics studies. The beamline is equipped with multiple spectrometers, supporting nuclear resonance fluorescence (NRF), photoneutron, and photon-induced charged particle reaction measurements. Recent scientific highlights include systematic (γ,1n) cross section measurements for ^{197}Au and ^{159}Tb that resolve long-standing discrepancies between previous Livermore and Saclay data [2]; the first systematic 2D mapping of the polarimetric distribution of linearly polarized gamma rays produced in relativistic Compton scattering at a finite scattering angle [3]; a high-precision measurement of the D(γ,n)p photodisintegration reaction with implications for Big Bang nucleosynthesis [4]; and the extraction of the sum of the electric and magnetic dipole polarizabilities of the deuteron based on a dense continuous dataset covering 2.33–19.65 MeV [5]. Beyond SLEGS, a new LCS source based on the Shanghai Soft X-ray Free-Electron Laser (SXFEL) is planned at SSRF, and a future source at SHINE is under consideration. This presentation will review SLEGS design, performance, operational status, user achievements, and emerging opportunities for the international community.

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KEYWORDS

SLEGS, SSRF, laser Compton scattering, photonuclear physics, gamma-ray source

A Nuclear AI4S Approach: Exotic Cluster Structures and Decays in Atomic Nuclei Driven by Dual-Agent Coupling

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ABSTRACT

We propose the "Theory-Data-Intelligence" paradigm driven by AI agents for microscopic calculations of nuclear systems. By coupling theoretical results with experimental feedback, we developed a dual-agent coupling framework to describe complex quantum states in light nuclei. This framework features two deeply coupled agents: the Control Neural Network (Ctrl.NN) extracts quantum features from high-dimensional many-body wave functions to predict imaginary-time evolution paths, efficiently guiding basis vector optimization; the Hamiltonian Generation Network (Ham.NN) uses experimental data as supervisory signals to adjust effective nuclear forces, ensuring physical self-consistency. We applied this framework to study the cluster structures and decay properties of ^{14}C and ^{17}F nuclei. By introducing high-momentum nucleon pairs to characterize the α-cluster dissolution effect, we constructed the CB-Brink wave function that incorporates both cluster and shell characteristics. In the study of ^{14}C, we successfully identified three 0^+ states with significant cluster components near the ^{6}He+α+α threshold. Analysis of the basis structures confirmed the existence of π- and σ-bond linear-chain states, and reaction channel analysis further revealed that the first 0^+ state above the threshold is a Bose-Einstein Condensation (BEC)-like state. Additionally, comparisons of partial decay widths derived from the *R*-matrix theory with experimental data provide crucial theoretical support for the experimental discovery of the BEC-like state. For ^{17}F, we investigated the excitation process from the ground-state shell structure to the cluster degrees of freedom in excited states. The results show that the theoretical branching ratios for α-decay and proton emission highly agree with the latest experimental data from the Institute of Modern Physics, verifying the exotic quantum phenomenon of shell-cluster phase coexistence near the ^{12}C+α+p threshold. By synergistically optimizing both high-dimensional wave functions and effective nuclear interactions, our dual-agent framework significantly simplifies the numerical calculations of quantum systems under multiple constraints, and offers a new perspective for solving the nuclear many-body problem.

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KEYWORDS

AI for Science, Nuclear Structure and Reaction Theory, Quantum Many-Body Systems, Exotic Cluster Structure, Bose-Einstein Condensation

Key intermediate state in the ^{11}B(p,α)$\alpha\alpha$ fusion reaction

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ABSTRACT

Proton-boron (^{11}B (p, α) $\alpha\alpha$) fusion, an ideal aneutronic reaction, is a promising next-generation clean energy. Precise calculations of cross-sections and S-factors for dominant resonance peaks are crucial for ignition prediction and reactor design. However, the two key intermediate ^{12}C states corresponding to these peaks lie above 16 MeV, a region scarcely explored in previous theoretical works. Employing the Control Neural Network (Ctrl.NN) based on the GCM, we systematically investigate the exotic structures and decay properties of these intermediate states (the 2^+ state at 16.1 MeV and the 2^- state at 16.6 MeV). Our model incorporates cluster-breaking configurations alongside 3α cluster wave functions, constructing a complex basis space of $\alpha+\alpha+^3$H+p, $\alpha+\alpha+^3$He+n, and 3α configurations, which is efficiently optimized via Ctrl.NN. This approach successfully identifies the key states above the ^{11}B+p threshold. RWA calculations reveal that while the 2^+ state is dominated by the ^{11}B+p component, the 3α configuration still contributes significantly to the α-decay RWA. Furthermore, R-matrix theory is applied to extract partial decay widths for the ^{11}B$(3/2^-)$+p and ^{8}Be$(0^+, 2^+)+\alpha$ channels. The derived S-factors and cross-sections successfully reproduce the magnitude of the 2^- resonance cross-section. This work establishes a robust theoretical framework for describing intermediate states and calculating cross-sections, deepening our understanding of fusion mechanisms and providing an effective approach for broader reaction studies.

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KEYWORDS
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