APS Global Physics Summit
Global Satellite Session - Ukraine: Quantum Science in Ukraine - 2025

March 18, 14-30
Room 322

PROGRAM

Theory assisted search for new quantum materials
Presented by Alexander Kordyuk (Kyiv Academic University), 14:30 – 14:42

Defining quantum materials as those with emergent quantum properties that enable their application in novel quantum devices, we are developing approaches for theory-assisted search for such materials. The foundation of this search lies in identifying key features of their electronic structure and combining methods for its prediction and experimental determination. Specifically, we employ machine learning algorithms to "recognize" the electronic structure of multiband superconductors (disentangling coherent and incoherent factors), calculate their electronic structure, and identify the most critical characteristics that determine both the practical applications of superconductors and the mechanism of superconductivity.

Altermagnetism Research at the German-Ukrainian Center for Quantum Materials
Presented by Jeroen Van den Brink (IFW Dresden), 14:42 – 14:54

This presentation highlights the German-Ukrainian Center for Quantum Materials (GU-QuMat) and focuses on one of its research directions: altermagnets. A significant number of altermagnetic materials have been predicted, with notable distinctions between their metallic and ionic forms. While metallic altermagnets are relatively rare, they exhibit intriguing properties. Ionic altermagnets, on the other hand, often feature large spin splittings. Predicted properties of altermagnets span a broad range, including spin-charge and spin-heat transport, piezomagnetism, anomalous Hall conductivity, Weyl semimetallicity, magnetic domain structures, and applications in curved nano-membranes. These findings underscore the rich potential of altermagnets for advancing quantum material science.

Modal approach to multi-parameters estimation in optics and the example of incoherent sources
Presented by Nicolas Treps (Sorbonne University), 14:54 – 15:06

Quantum optical metrology aims at identifying the ultimate sensitivity bounds for the estimation of parameters encoded into an optical field. In many practical applications, such as imaging, microscopy, and remote sensing, the parameter of interest is encoded not only in the quantum state of the field but also in its spatio-temporal distribution, i.e., in its modal structure. In this context, we propose both a theoretical framework and an experimental approach to derive bounds and perform measurements that are quantum-optimal, either in the single or in the multi parameter settings. We illustrate this with the example of multi-parameter estimation on two incoherent sources.

Nonclassical steering in quantum optics
Presented by Andrii Semenov (Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine), 15:06 – 15:18

Optical nonclassicality is considered as the impossibility to represent quantum states as statistical mixtures of coherent states. Furthermore, it is considered as an important example of quantum resources needed, e.g., for the generation of entanglement with passive linear optics, as well as for tasks in quantum metrology and non-universal quantum computing. We consider a scenario where the informational incompleteness of quantum measurements is insufficient to reveal optical nonclassicality [1]. It turns out that even in such a scenario for the case of states conditionally prepared on one mode of optical radiation by a measurement on another mode, we can still extract some information about nonclassicality. This task can be performed by a proper analysis of nonclassical steering---a class of quantum correlations beyond quantum entanglement and discord for which we introduce a rigorous description [2].

References:

[1] V. S. Kovtoniuk, E. V. Stolyarov, O. V. Kliushnichenko, and A. A. Semenov. Tight inequalities for nonclassicality of measurement statistics. Phys. Rev. A 109, 053710 (2024).
[2] V. S. Kovtoniuk, A. B. Klimov, A. A. Semenov. Latent optical nonclassicality of conditionally-prepared states, arXiv:2408.04740 [quant-ph] (2024).

Unravelling the Hydrogen Bonding Patterns in Telomeric G-quadruplexes: From Structure to Function-Paradigm of Aging
Presented by Eugene Kryachko (Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine), 15:18 – 15:30

The paradigm of aging is now on every-one's lips and thoughts. The cure for aging has long been the Holy Grail of medicine that these days was joined by physics and quantum chemistry. How we age, what diseases we will get, and how long we will live - all this is determined by our genes. Chromosomes are tightly packed DNA structures that carry our genetic code, a kind of body construction plan. Normal human cells contain 46 chromosomes. Just as rivets on shoelaces prevent chromosomes' ends from fraying, telomeres secure the ends of chromosomes as caps, so that their sequences do not get tangled. Back in the 1960s-70s, it became clear that telomeres gradually shorten during cell division, and when they reach their critical length, the cell stops dividing, ages, and dies. So, telomeres are a kind of cell division counter that determines a person's biological age. In 2009, the Nobel Prize in

Physiology or Medicine was awarded to E.H. Blackburn, C.W. Greider, and J.W. Szostak "for the discovery of how chromosomes are protected by telomeres ...". Actually, they solved a major problem in biology of how the chromosomes can be copied in a complete way during cell divisions and how they are protected against degradation. It was demonstrated that the solution is to be found in the caps of the chromosomes – the telomeres – and in an enzyme that forms them – telomerase: the long, thread-like DNA molecules that carry our genes are packed into chromosomes, capped by telomeres. The latter contain G(guanine)-rich repeat sequences that are capable to fold into four-stranded so-called G-quadruplexes or G4 structures. In this work we investi- gate the molecular basis of the telomere model of aging. Its key trait is the hydrogen (H-) bonding patterns of G-tetrads that serve a top of G-quadruplexes composing telomeres. We show that these patterns demonstrate a variety of bonding characters – from classic hydrogen bonds to so called 'over-coordinated oxygen (OCO)' bifurcated H-bonds that thus result in floppiness of G-tetrad structures. This work has implications for the functionality of G-quadruplexes and, in turn, for the quadruplex-based telomere model of aging.

Alchemy as an optical problem: Theory and Experiments
Presented by Denys Bondar (Tulane University), 15:30 – 15:42

Using tracking quantum control, we theoretically unveiled an unexplored flexibility of nonlinear optics that a shaped laser pulse can drive a quantum system to emit light as if it were an arbitrary different system. This realizes an aspect of the alchemist's dream to make different elements look alike, albeit for the duration of a laser pulse. This finding has received broad public coverage in such scientific outlets as Physics, PhysicsWorld, Nature Materials, Quanta Magazine, Wired, etc. We will show how this unexplored flexibility of nonlinear optics opens new venues of investigation that include ultrafast artificial intelligence, chemical mixture characterization, and broadband ENZ materials with infinite phase velocity of light. Based on these theoretical insights, recent experimental results will be presented, showing how water can be transformed into alcohol and how ENZ materials can be dynamically created.

Spectral gaps of 2D and 3D quantum many-body systems in thermodynamic limit
Presented by Andrii Sotnikov (Kharkiv Institute of Physics and Technology), 15:42 – 15:54

We present an expression for the energy gap between the ground and the first exited state of quantum many-body systems, opening up new prospects for performing and accelerating spectral calculations. We develop and demonstrate one such possibility in the context of tensor network simulations. Our approach requires only minor modifications of the widely used Simple Update method and is computationally lightweight relative to other approaches [1].

The work is supported by the National Research Foundation of Ukraine under the call "Excellent science in Ukraine", grant No. 0124U004372.

References:

[1] I. V. Lukin, A. G. Sotnikov, J. M. Leamer, A. B. Magann, D. I. Bondar, Spectral Gaps of 2D and 3D Many-body Quantum Systems in the Thermodynamic Limit, Phys. Rev. Research 6, 023128 (2024), https://doi.org/10.1103/PhysRevResearch.6.023128

Implementing quantum signal processing with adiabatic-impulse model
Presented by Sergey Shevchenko (Kharkov University), 15:54 – 16:06

Quantum Signal Processing (QSP) is an algorithm that uses single-qubit dynamics to perform almost any polynomial function transformation with basic unitary operations. The Adiabatic-Impulse Model (AIM) effectively describes the evolution of a two-level quantum system under an external driving field. QSP can directly use parameters from the AIM by mapping AIM's smooth drive profiles to the phase angles in QSP. By defining AIM parameters that control adiabatic transitions such as amplitude, frequency, and signal time one can guide the smooth variation of QSP phases to achieve stable polynomial approximations or mitigate errors in quantum circuits. That demonstrates the analogy between QSP and AIM and can be useful as a way to directly implement the QSP algorithm on quantum systems.

Detection characteristics of networks and properties of spin systems on a quantum computer
Presented by Khrystyna Gnatenko (Ivan Franko National University of Lviv), 16:06 – 16:18

Multi-qubit quantum states representing directed networks are studied. These states are considered to be evolutionary quantum states of spin systems described by the Ising model with spatially anisotropic interactions. The geometric measure of entanglement for these states has been calculated for arbitrary structures of weighted and directed graphs [1]. A relationship has been established between the entanglement of quantum network states and the properties of the corresponding networks, including the weights of incoming and outgoing arcs, as well as the outdegree and indegree of vertices [1].

Additionally, a relationship has been identified between the properties of spin systems, their quantum states (energy fluctuations, coupling constants, velocity of quantum evolution, and geometric characteristics of evolutionary quantum states) and graph properties, including the sum of the weighted degrees of nodes, the sum of products of edge weights forming triangles and squares, the number of triangles and squares in the graph [2,3]. Quantum algorithms for detecting network properties have been proposed. Based on these findings, the properties of specific network cases and their corresponding quantum network states were calculated on IBM's quantum devices [2,3].

A quantum algorithm for detecting the energy levels of spin systems, based on the study of the evolution of a probe spin, has been proposed. The energy levels of spin systems described by the Ising model were determined using quantum programming on IBM's quantum computers [4].

References:

[1] Kh. P. Gnatenko, Physics Letters A 521, 129815 (2024).
[2] Kh. P. Gnatenko, H. P. Laba, V. M. Tkachuk, Physics Letters A 452, 128434 (2022).
[3] Kh. P. Gnatenko, Relation of curvature and torsion of weighted graph states with graph properties and its studies on a quantum computer, arXiv:2408.01511 (2024).
[4] Kh. P. Gnatenko, H. P. Laba, V. M. Tkachuk, Eur. Phys. J. Plus 137(4), 522 (2022).

Efficient utility-scale encoding of data and distributions on a Quantum Computer

Presented by Mykola Maksymenko (Haiqu Ukraine LLC), 16:18 – 16:30

Data loading is a crucial initial step in practical quantum computations, especially in finance where precise representation of complex probability distributions is vital. Most common methods for encoding these distributions tend to result in exponentially deep quantum circuits, rendering them impractical on current noisy hardware. We introduce an improved algorithm that constructs efficient, provably linear-depth shallow quantum circuits for encoding data and probability distributions, including heavy-tailed distributions such as Lévy distributions. This approach significantly reduces circuit depth, thus reducing hardware noise impact, and enhancing feasibility for real-world applications. We have validated our method on both simulated and real IBM quantum devices, including the 127-qubit Heron Quantum Processing Unit, demonstrating efficiency and scalability.