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BOGOLIUBOV LABORATORY
OF THEORETICAL PHYSICS
EXPLORING THE LAWS OF NATURE FROM QUANTUM TO COSMOS

SMHS – 2025

Book of Abstracts

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BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

EXPLORING THE LAWS OF NATURE FROM QUANTUM TO COSMOS

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Resonance phenomena and Kapitza pendulum effects in a nanomagnet coupled to a Josephson junction and under external radiation.

K. V. Kulikov[1,2], D. V. Anghel[1,3], M. Nashaat[1,4], M. Dolineanu[3,5], M. Sameh[1,4], and Yu. M. Shukrinov[1,2,6]

[1]BLTP, JINR, Russia
[2]Dubna State University, Russia
[3]IFIN-HH, Romania
[4]Department of Physics, Faculty of Science, Cairo University, Egypt
[5]University of Bucharest, Romania
[6]Moscow Institute of Physics and Technology, Russia

Corresponding Author: D. V. Anghel

Email: dragos@theor.jinr.ru

We investigate the dynamic response of a hybrid system composed of a nanomagnet coupled to a Josephson junction under an external periodic drive. Our work explores two key phenomena arising from this interaction: the emergence of new resonance peaks and the controlled reorientation of the nanomagnet's easy axis.

First, we show that the coupling gives rise to additional resonance peaks whose properties are tunable via the external signal and the Josephson junction dynamics. We present a universal analytical method, confirmed by numerical simulations, to describe these resonances. Second, we demonstrate that the high-frequency drive can reorient the nanomagnet's magnetization, a behavior analogous to the stabilization of an inverted Kapitza pendulum. The combined magnetic fields from the junction and the drive act as the oscillating force. We derive simple analytical formulas for the stable orientation of the magnetic moment and show that the external drive influences the voltage required for complete reorientation.

Together, these findings provide a comprehensive framework for controlling the dynamic properties of nanomagnet-Josephson junction hybrids, which is promising for applications in spintronics and sensing. More details can be found in [1, 2].

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Domain wall superconductivity in van der Waals structures with ferroelectric ordering

D.S. Annenkov [1], A. A. Kopasov [2], A. S. Mel'nikov [1,3]

[1]Moscow Institute of Physics and Technology (National Research University), Dolgoprudnyi, 141701 Moscow Region, Russia
[2]National University of Science and Technology "MISIS", Moscow 119049, Russia
[3]Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105 Russia

Corresponding Author: D. S. Annenkov

Recently, there has been huge interest in the physics of low-dimensional van der Waals structures and the related interplay between various types of ordering (superconductivity, ferroelectricity). This work demonstrates that the structure of superconducting correlations in van der Waals systems can be strongly affected by the nonlocal nature of electron attraction, which can lead to the formation of Cooper pairs composed of electrons localized in different layers of a hybrid structure [1–5]. These issues are explored for a model bilayer system in the presence of tunneling and relative shifts of the energy bands in the layers caused by spontaneous polarization oriented perpendicular to the layers [6].

We found that for a stepwise relative band shift, spin-singlet superconducting states exist, which are localized at such a domain wall and have a critical temperature higher than that of the uniform superconducting state. It is shown that the tunneling between the layers strongly modifies the system phase diagram, suppressing the singlet domain wall superconductivity. The possibility of such localized superconducting states with spin-triplet structure is discussed.

The obtained results are discussed in the context of recent experimental data on the coexistence of ferroelectricity and superconductivity in van der Waals bilayers [7].

Acknowledgment:
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High-performance numerical study of physical characteristics of superconducting Josephson structures in dependence of parameters of the models

M. V. Bashashin[1,2], I. R. Rahmonov[1,2], E. V. Zemlyanaya[1,2]

[1]Joint Institute for Nuclear Research, Dubna, Russia 141980,
[2]Dubna State University, Dubna, Russia, 141980

Corresponding Author: M.V. Bashashin

Email: bashashinmv@jinr.ru

Methods and software packages for the parallel implementation of studying two models of superconducting structures are presented. The first model describes a system of coupled long Josephson junctions taking into account the inductive and capacitive coupling between neighboring junctions and electromagnetic radiation from their boundaries. The second model describes the φ_0 junction with spin-orbit coupling in a ferromagnetic layer and a pulsed current source acting on it.

The developed parallel computing methods made it possible to successfully study the physical characteristics in these models in a wide range of parameters. The parallel software packages have been deposited to the JINR program library and are freely available. The calculations were performed on the HybriLIT computing resources of the JINR Multifunctional Information and Computing Complex.

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Anomalous Josephson effect and superconducting diode effect in Josephson junctions via RET2Si2 intermetallic magnets

G.A. Bobkov [1], I.A. Shvets [2], A.M. Bobkov [1], S.V. Eremeev [3], I.V. Bobkova [1], E.V. Chulkov [4]

[1]*Moscow Institute of Physics and Technology, Dolgoprudny, Russia*
[2]*Tomsk State University, Tomsk, Russia*
[3]*Institute of Strength Physics and Materials Science RAS, Tomsk, Russia*
[4]*Donostia International Physics Center, 20018 Donostia-San Sebastian, Basque Country, Spain*

Corresponding Author: A. M. Bobkov

Email: ambobkov@mail.ru

In this talk, the anomalous Josephson effect in S/F/S junctions with strong spin-orbit coupling is discussed. In such systems, a direct magnetoelectric coupling arises between the magnetic moment of the ferromagnetic weak link and the phase of the superconducting condensate. This allows one to control the magnetization of the weak link and switch it using supercurrent pulses [1]. In addition, in a coupled chain of Josephson S/F/S junctions with an anomalous phase shift of the ground state, a long-range interaction between the magnetic moments of the weak links is predicted [2], which makes this system suitable for studying collective magnetic states controlled by the superconducting phase [3,4]. Also in the talk, based on the results of first-principles calculations of the electronic structure of ferromagnetic films of RET2Si2 intermetallic magnets, where RE - rare earth, T - transition metal [5], and subsequent calculations of the Josephson current through weak links made of them, it is demonstrated that Josephson junctions through such materials are a natural platform for the experimental implementation of magnetoelectric coupling between the magnetic moment and the phase of a superconducting condensate. The results of the calculations of CPRs are presented. The combination of ferromagnetism and strong spin-orbit interaction results in two key properties of the CPRs. First of all, the CPRs manifest the anomalous phase shift depending on the magnetization direction, which allows for the control of the magnetization by the Josephson phase. Second, the superconducting diode effect occurs, i.e., the critical Josephson current is different when passing electric current in opposite directions. The efficiency of the superconducting diode effect is quite high and reaches several tens of percent.

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Numerical simulation for the design of superconducting neurons

V. V. Bol'ginov[1], L. N. Karelina[1], N. S. Shuravin[1], F. A. Razorenov[1,2], A. S. Ionin[1,2,3], I. E. Tarasova[1,2], M. M. Khapaev[1,4]

[1]*Osipyan Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow region, 142432 Russia*
[2]*Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, Moscow Region, Russia*
[3]*"Joint Venture "Quantum Technologies," Moscow, 121205 Russia*
[4]*Moscow State University, Moscow, Russia*

Corresponding Author: V. V. Bol'ginov

Email: bolg@issp.ac.ru

Adiabatic superconducting neurons are single- and double-junction interferometers, shunted with additional inductance. The required shape of the activation function is achieved at certain values of the inductance of the parts of the neuron. Therefore, numerical modeling of the sample design is of great importance, since it allows for the calculation of the necessary values and predicts the shape of the transfer function. Currently, there are several programs for this purpose, two of which were developed [1-2] by one of the co-authors.

We report the first systematic study of the applicability of wxLL and 3D-MLSI programs for designing Josephson interferometers. We have calculated the inductance of the loops of two-junction interferometers placed above a superconducting screen. Then, a comparison was made with the results of an experimental study of samples fabricated using the USE «Cryointegral» (USE No. 352529) of the V.A. Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences. The good coincidence of calculated and experimental data allows us to expect the successful implementation of neuromorphic Josephson interferometers. Obtained experimental temperature dependencies reveal the possibility to adjust the superconducting sigma-neuron transfer function.

Acknowledgment: The work was supported by the Russian Science Foundation, project no. 23-72-00053.

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Bulk-edge correspondence at the spin-to-integer quantum Hall effect crossover in topological superconductors

M.V. Parfenov[1], I.S. Burmistrov[1]

[1]L.D. Landau Institute for Theoretical Physics RAS, 142432 Russia, Chernogolovka, acad. Semenova str. 1a

Corresponding Author: I. S. Burmistrov

Email: burmi@itp.ac.ru

In this work, we investigate the behavior of a two-dimensional topological superconductor with broken time reversal symmetry under the influence of a parallel magnetic field (Zeeman splitting) that breaks spin rotational symmetry. Recently, such a two-dimensional topological superconductor has been realized in twisted Bi2Sr2CaCu2O(8+x) bilayers [1]. Such a problem is of fundamental interest since Zeeman splitting drives the crossover between two non-trivial topological regimes: the spin quantum Hall effect (sqHe) and the integer quantum Hall effect (iqHe).

Since both sqHe and iqHe are supported by the existence of edge modes, we first examine how these edge modes transform in the course of the crossover. We demonstrate peculiarities of the bulk-edge correspondence (which is believed to be an important feature of topological phases) at the crossover. In particular, we find that the sqHe-to-iqHe crossover does not occur when the symmetry-breaking magnetic field is applied only at the edge of a topological superconductor. We showed that the sqHe-to-iqHe crossover requires the presence of Zeeman splitting in the bulk of the system.

From the theoretical side, the sqHe-to-iqHe crossover is of interest since there exist topological excitations (instantons) in both phases. Through the exact calculations, we demonstrate that the crossover suppresses the sqHe instantons with odd integer topological charge, while instantons with even integer topological charge turn into a pair of iqHe instantons with half of the original topological charge each. These transformations of bulk topological excitations affect the phase diagram, structure of the iqHe plateaus, and dependence of physical observables on bare parameters of the theory.

Results are published in [2].

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Superconducting orbital diode effect in SN bilayers

Yu. A. Dmitrievtsev[1, *], Ya. V. Fominov[1,2]

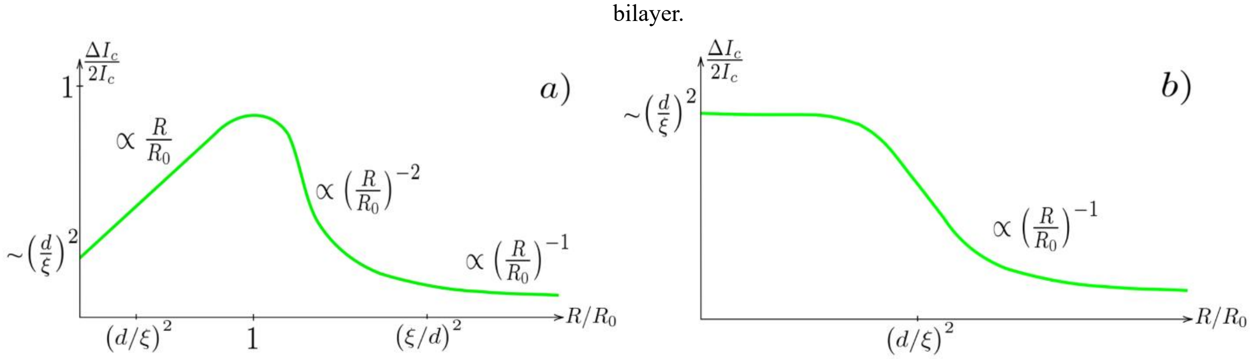
[1]L. D. Landau Institute for Theoretical Physics RAS, 142432 Chernogolovka, Russia
[2] Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia

Corresponding Author: Yu. A. Dmitrievtsev

Email: dmitrievtsev.iua@phystech.edu

In superconducting hybrid structures with broken geometric symmetry and symmetry with respect to time reversal, a diode effect occurs, which consists of different critical currents when a supercurrent flows in different directions. The system we are considering is an SN bilayer – two layers of superconductor (S) and normal metal (N) brought into contact. The bilayer is located in an external parallel magnetic field. The properties of the supercurrent flowing along the bilayer perpendicular to the magnetic field are studied. In 2023, an article [1] was published on the study of the diode effect in such a structure. In it, this effect in the MoN/Cu bilayer was studied numerically and experimentally. Numerical calculation and experiment were carried out for a bilayer with a thickness of each layer on the order of several coherence lengths, but thin compared to the London penetration depth, in the dirty limit, allowing the application of the Usadel equations. The fact that the thickness of the layers is of the order of the correlation length leads to a nontrivial distribution of the order parameter, and hence the concentration of superconducting electrons along the thickness of the sample. This makes the problem analytically unsolvable in the general case. Our goal is to consider a similar system in extreme cases that allow an analytical solution, in which, nevertheless, many qualitative patterns for critical currents are preserved, as well as to consider the effect of interface resistance on the diode effect. In particular, the dependence of critical currents on the magnetic field is found. A nonmonotonic dependence of the efficiency of the diode effect on the resistance of the interface, with the maximum at a certain optimal resistance, has also been established.

Fig. 1. Dependence of the strength of the diode effect on the dimensionless resistance of the boundary in the cases of: a) thin b) thick bilayer.



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Experimental implementation of elements of superconducting bio-like neurons based on Nb/Au/Nb Josephson junctions

Elistratova A. A. [1,2], Gubochkin G. I. [3], Shishkin A.G. [1,2], Bakursky S. V. [2,3], Klenov N. V. [2,3], Stolyarov V. S. [3],

[1] *Moscow Institute of Physics and Technology, 141701, Russia*
[2] *Federal State Unitary Enterprise VNIIA named after. N.L. Dukhova, 127055, Russia*
[3] *Moscow State University, 119991, Russia*

Corresponding Author: A. A. Elistratova

Email: elistratova.aa@yandex.ru

The development of neural network models on biosimilar spiking neurons represents a cutting-edge direction in artificial intelligence research. These systems are anticipated to deliver more efficient parallel information processing and exhibit greater adaptability to changing environments. However, a significant limitation persists: the core components used in the fastest and most energy-efficient Josephson-based implementations currently have planar dimensions that are too large, which constrains the scalability of such architectures.

In this work, we investigate the practical viability of using Josephson junctions with a weak normal region (SNS type) as a way to overcome these miniaturization challenges for biosimilar Josephson neurons [1, 2]. To this end, Nb/Au/Nb SNS junctions and a two-junction SQUID were fabricated. Experimental measurements were performed in a dilution refrigerator capable of reaching temperatures as low as 0.2 K. The devices were connected in a four-terminal DC configuration (Fig. 1a). We studied the current-voltage characteristics (CVCs) of the samples across a range of temperatures up to the superconducting critical temperature Tc=9.2T_c = 9.2 K, and in magnetic fields up to 3.5 T. In addition, the SQUID parameters were investigated under applied bias currents (Fig. 1b).

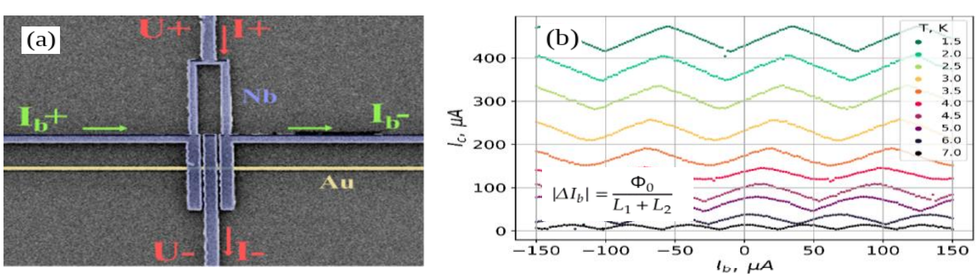

Fig. 1: Two-contact SQUID: (a) – photo taken with SEM; (b) - the dependence of the critical current on the flux induced by the bias current $I_c(I_b)$.

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DC and AC study of anisotropic transport properties in the topological insulator $Bi_{1.06}Sn_{0.04}Sb_{0.9}Te_2S$

Enderova T.N.[1], Sakhin V.O.[1], Gimazov I.I.[1], Kukovitsky E.F.[1], Talanov Yu.I.[1]

[1]Zavoisky Physical-Technical Institute, FRC Kazan Scientific Center of RAS, Russia

Corresponding Author: T. N. Enderova

Email: tenderova101@mail.ru

Topological insulators (TIs) are quantum materials characterized by an insulating bulk and conducting surface states. Among the most studied TIs are bismuth chalcogenides. However, these materials typically possess a high density of bulk charge carriers, which complicates the study of surface transport properties. Bulk carrier suppression can be achieved through atomic substitution and chemical doping. One of such engineered compounds is $Bi_{1.06}Sn_{0.04}Sb_{0.9}Te_2S$ (BSSTS) [1]. In this system, the dominant contribution to DC transport depends on temperature: bulk conduction dominates above 100 K, while surface conduction becomes decisive below 100 K.

In this study, we employed both DC and AC measurements to investigate the transport properties of BSSTS crystals. Non-resonant microwave absorption at 9.4 GHz was used as the AC technique, it was performed using the Bruker BER 418S X-band EPR spectrometer. We measured the temperature dependence of the non-resonant microwave absorption amplitude, $A_{\mathrm{MWA}}(T)$, for two orientations of the BSSTS flakes relative to the magnet component of the microwave field. Depending on the sample orientation, the induced current flows either parallel or perpendicular to the flake surface. We have observed significant differences in transport behavior between these configurations.

In the standard configuration with current flowing in the *ab*-plane, we observed the expected competition between semiconducting bulk behavior and metallic surface conduction. In contrast, when the current flowed perpendicular to the ab-plane, the temperature dependence became more complex. In particular, in the temperature range where bulk conduction dominates, a local maximum appeared in the $A_{MWA}(T)$ curve. This may indicate a transition in the prevailing scattering mechanism – from impurity scattering to phonon scattering. While in-plane transport (when current flows in the *ab*-plane) is governed only by phonon scattering at temperatures above 100 K.

Complementary DC measurements of resistance $R(T)$ revealed qualitatively similar results. However, a notable difference emerged: in the AC measurements, the temperature corresponding to the resistance maximum was shifted to higher values. The origin of this shift comes from the influence of high frequency on transport properties for disordered materials [3].

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Superconducting diode effect

Ya. V. Fominov[1,2]

[1]L. D. Landau Institute for Theoretical Physics RAS, 142432 Chernogolovka, Russia
[2] Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia

Corresponding Author: Ya. V. Fominov

Email: fominov@itp.ac.ru

I will present a concise overview of the rapidly developing field of nonreciprocal effects in superconducting transport, also known as the *superconducting diode effect*. The essence of this phenomenon lies in the asymmetry of a system's properties when a supercurrent flows in opposite directions. Such an effect requires the simultaneous breaking of time-reversal and inversion symmetries. The underlying physical mechanisms can vary significantly, including effects of magnetic (and, more specifically, exchange) fields, spin-orbit interactions, and geometric asymmetry of the system. These effects can lead to nonreciprocal charge transport both in systems homogeneous along the current direction and in Josephson junctions.

The work was supported by the Russian Science Foundation (Grant No. 24-12-00357).

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Controllable supercurrent and 0-π transition via quasiparticle injection in mesoscopic multiterminal SNS Josephson junctions

I.A. Nazhestkin [2,3], T.E. Golikova [1], S.V. Egorov[1,3], A.G. Shishkin[2], I.E. Batov[1] and V.V. Ryazanov[1,2]

[1] *Insitute of Solid State Physics RAS, 2 Akademika Osipyana street, Chernogolovka, 142432, Russia*
[2] *Moscow Institute of Physics and Technology, 9 Institutskiy lane, Dolgoprudny, 141701, Russia*
[3] *Russian Quantum Center, 30 Bolshoy Boulevard, building 1, Skolkovo Innovation Center territory, Moscow, 121205, Russia*

Corresponding Author: T. E. Golikova

Email: golt2@list.ru

We have observed a return behavior of the supercurrent associated with 0-π transition in mesoscopic S-N-S Josephson junction (*Al-Cu-Al*) controlled by the injection of nonequilibrium quasiparticles from the N-electrode (*Cu*) connected to the one of superconducting banks of the junction [1] very close to the Josephson barrier at the distance of the order of superconducting coherence length ξ_S. In another injection case when the distance from N-electrode to the junction was sufficiently lager 0-π transition was not observed. Temperature dependencies of the critical current versus the injection current were investigated in both cases. It was found that 0-π transition disappears at $T/T_c \approx 0.6$. These results were compared with our experimental results obtained for the *Al-Cu-Al* Josephson junctions realized in cross-like geometry investigated by J.J.A. Baselmans *et al* [2].

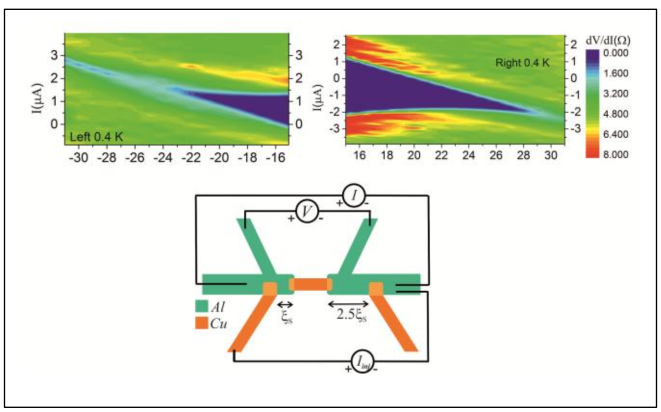

Fig. 1. The color-scaled differential resistance dV/dI as a function of injection current I_{inj} from the nearest left injector (left side), the far-right injector (right side) and bias current I of the junction at temperatures T=0.4 K with the measurement scheme.

Acknowledgment: The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation for ISSP RAS

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Full counting statistics for unconventional superconductor junctions

A.A. Golubov [1]

[1] *Moscow Institute of Physics and Technology, Dolgoprudny, Moscow district, Russia*

Corresponding Author: A. A. Golubov

Email: a.golubov1960@gmail.com

Noise and current measurements are key tools for studying mesoscopic systems, revealing insights beyond conductance alone. For instance, noise measurements show that transport carriers in conventional superconductors have charge 2e. The noise power also depends on junction type, distinguishing different transport processes. Existing theories focus primarily on zero temperature shot noise in tunnel junctions with conventional superconductors, where transport is carried by quasiparticles and Cooper pairs.

Here we develop a full counting statistics theory for unconventional superconductor / normal metal junctions of different types, incorporating the effect of thermal noise on the differential Fano factor, the ratio of differential noise power and conductance. In these junctions there is a third type of transport mechanism, surface Andreev bound states. Our study reveals that junctions with dispersionless surface Andreev bound states exhibit negative differential Fano factor at finite temperatures. In contrast, in the presence of dispersive surface Andreev bound states, the noise power always increases with voltage, but there are local minima in the differential noise at those voltages corresponding to the extrema of the surface Andreev bound state spectrum. For normal metals and conventional superconductors the voltage dependence of the differential Fano factor is similar in all types of junctions, including tunnel junctions and diffusive barriers. However, significant differences arise with unconventional superconductors, making distinct junction types valuable tools for identifying pairing symmetries. Our results highlight the importance of finite temperature effects in noise power measurements for potential unconventional superconductors, offering new means to determine pairing symmetries in topological superconductors.

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Progress of implementation of the superconducting neuron prototype

A.S. Ionin[1,2]*, F.A. Razorenov[1,2], S.V. Egorov[1], L.N. Karelina[1], N.S. Shuravin[1], I.E. Tarasova[1,2], V.V. Bolginov[1].

[1]Institute of Solid State Physics, Russian Academy of Sciences Akademika Osip'yana St. 2, Chernogolovka, Moscow Region, 142432, Russia
[2]Moscow Institute of Physics and Technology (National Research University)

Corresponding Author: A. S. Ionin

Email: ionin.as@phystech.edu

In recent years, artificial neural networks (ANNs) have been increasingly applied across various fields. The key component of neuromorphic systems is a neuron, which performs signal normalization. Two types of neurons are most widely used: those with a sigmoidal activation function (σ-neuron) and those based on a Gaussian distribution (γ-neuron). As the volume of data and the number of parameters in neural networks grow, so do computational costs and training time. This drives the search for new approaches to implementing neuromorphic systems. One promising direction is the use of superconducting Josephson structures, which offer several advantages over semiconductor-based analogs. Superconducting interferometers enable higher signal processing speeds and can be employed in adiabatic computing, significantly reducing power consumption. This work presents experimental results on the implementation of σ- and γ-neurons [3–4], previously proposed in studies [1–2]. The samples are multilayer thin-film structures forming superconducting loops with one (σ-neuron) or two (γ-neuron) tunnel Josephson junctions. Based on an analysis of the transfer functions, algebraic equations describing the interaction between the samples and the driving/readout elements were derived. Special attention was given to accounting for all components of the inductance matrix in the proposed topology. The matrix was calculated using specialized software (3D_MLSI and wxLL) [5]. As a result, good agreement between simulated and measured characteristics was achieved.

Acknowledgment: The research was conducted at the Institute of Solid-State Physics of the Russian Academy of Sciences (ISSP RAS) with support from the Russian Science Foundation (grant No. 23-72-00053).

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Nonreciprocal phenomena in the asymmetric superconducting interferometer with external microwave irradiation

Dmitrii S. Kalashnikov [1 *], Gleb S. Seleznev [1,2] , Yakov V. Fominov [1,2,3], Vasily S. Stolyarov [1, 4]

[1] *Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia*
[2] *L.D. Landau Institute for Theoretical Physics RAS, 142432 Chernogolovka, Russia*
[3] *Laboratory for Condensed Matter Physics, HSE University, 101000 Moscow, Russia*
[4] *Dukhov Research Institute of Automatics (VNIIA), 127055 Moscow, Russia*

Corresponding Author: D. S. Kalashnikov

Email: kalashnikov.ds@phystech.edu

The superconducting diode effect has recently garnered significant attention due to its importance in fundamental research and its promising applications in superconducting electronics [1]. SQUIDs are commonly employed to investigate this effect, as their geometry allows for easy implementation of asymmetry and the breaking of time-reversal symmetry via an external magnetic field.

In our study, we examine a SQUID deliberately fabricated from two qualitatively different types of Josephson junctions: one is a superconductor–normal metal–superconductor (SNS) junction, and the other is a nanobridge exhibiting a linear, multivalued current-phase relation [2]. The primary manifestation of the diode effect—an asymmetry in the critical current—reaches 3% in our system. However, this work extends beyond conventional measurements by highlighting additional features in the current-voltage (I–V) characteristics, particularly the emergence of Shapiro steps under external microwave irradiation [3]. We observe that in our setup, the Shapiro steps exhibit a markedly stronger asymmetry than the critical currents—9% compared to 3%. Furthermore, the diode effect observed in the Shapiro response oscillates with the magnetic field, following the SQUID’s periodicity, and behaves non-monotonically on the applied power.

Our experimental data enabled the development of a theoretical model that qualitatively reproduces these effects, offering deeper insight into nonreciprocal behavior in superconducting systems and potential applications across various devices and materials.

Acknowledgment:
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Finite difference balance method for discontinuous solutions of the Usadel equations

M.M. Khapaev[1,2], M. Yu. Kupriyanov [2]

[1]*Lomonosov Moscow State University, VMK, Dep. of Numerical Methods, Russia*
[2]*Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Russia)*

Corresponding Author: M. Khapaev

Email: vmhap@cs.msu.ru

The paper considers a one-dimensional problem for Usadel elliptic equations with nonstandard jump conditions on the inner boundary and a discontinuous solution. The integro-interpolation (balance) method is used for finite difference approximation, including the junction condition on the inner boundary where jump of the solution is proportional to the flux. This difference scheme is used to solve the system of nonlinear Usadel equations, which is the basic mathematical model at the microlevel for describing currents and fields in superconductors, including those with Josephson junctions. This scheme solves the problem of finding the structure of an Abrikosov vortex whose center is located on the axis of a superconducting cylinder. The direction of the magnetic field is parallel to its axis. The cylinder is located inside a superconductor matrix. It is made of the same superconductor material, but it is separated from it by a sharp boundary having a finite transparency. The mathematical model under consideration describes the structure of an Abrikosov vortex in a granular superconducting film whose granule size is comparable to the coherence length of the superconductor. The results of calculations for the Abrikosov vortex problem are presented and the accuracy of the proposed approach is investigated.

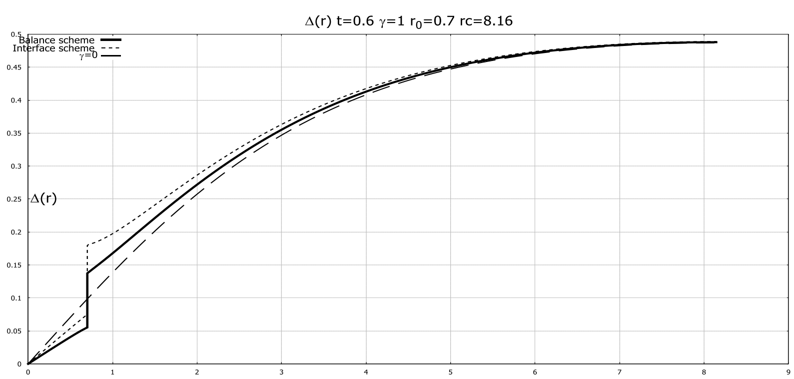

Fig. 1. Order parameter function Δ(r) [1] calculated with standard jump approximation [2], improved balance approximation of this work and Δ(r) without jump. Balance approximation is more physically accurate.

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Josephson oscillator for on-chip qubit excitation and two-tone spectroscopy

M. M. Khrenov,[1,3,4] R. D. Yusupov,[1,3] G. I. Gubochkin,[1,3] V. A. Vozhakov,[1,4] I. A. Nazhestkin,[1,2,4] A. D. Belanovsky,[4] P. A. Gladilovich,[5] G. S. Khismatullin,[1,3] M. Yu. Kuprianov,[3] V. P. Koshelets,[6] V. V. Ryazanov,[1] N. A. Maleeva,[5] N. V. Klenov,[1,3] I. I. Soloviev[1,3] & D. S. Yakovlev[7]

[1] Russian Quantum Center, Skolkovo, Moscow Region 143027, Russia;
[2] Moscow Center for Advanced Studies, Kulakova str. 20, Moscow 123592, Russia
[3] Lomonosov Moscow State University, Slobeltsyn Institute of Nuclear Physics, Leninskie gory, GSP-1, Moscow 119991, Russia;
[4] Quantum Foundation Center of Nanofabrication, Volgogradsky prospect 58, Moscow, 109316, Russia;
[5] National University of Science and Technology MISIS, 119049 Moscow, Russia
[6] Kotelnikov Institute of Radioengineering and Electronics, 11 bld. 7, Mokhovaya st., Moscow 125009, Russia;
[7] Laboratoire de Physique et d'Etude des Mat ´eriaux, ESPCI-Paris, PSL Research University, 75005 Paris, France

Corresponding Author: M. M. Khrenov

Email: khrenov.mm@gmail.com

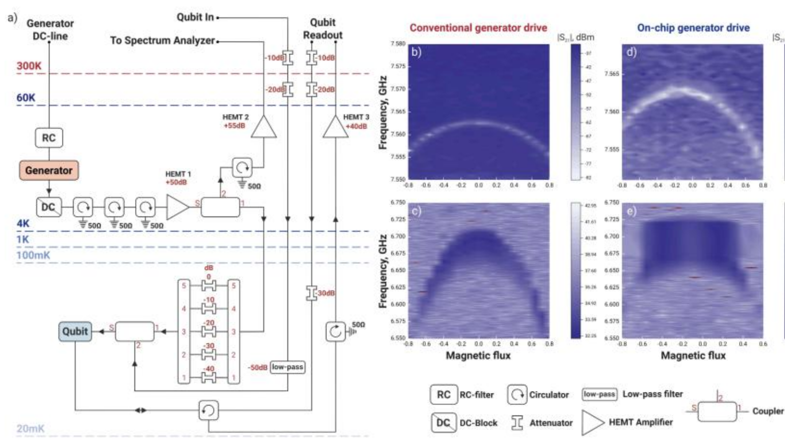

Fig. 1. a) experimental setup for the qubit excitation with the on-chip Josephson source; b,c) single-tone and two-tone spectroscopy of the qubit-resonator system with a room source; d,e) single-tone and two-tone spectroscopy of the qubit-resonator system with a cryogenic Josephson junction-based source.

Progress in the development of quantum computing technologies gradually leads to an increase in the scale of quantum circuits located on a chip at typical temperatures from several K to tens of mK. This leads to an increase in the number of expensive microwave equipment located at room temperature, which itself is a source of noise for quantum circuits. To increase the energy efficiency of the devices under consideration, it is proposed to transfer to the chip the main microwave elements including local oscillator.

In this work we show the device based on the resistively and capacitively shunted Josephson junction embedded into a resonator which can be used as a cryogenic qubit driver [1-4]. The external resonant circuit is used to reduce the radiation bandwidth and suppress unwanted transitions in the qubit. We characterize the device by measuring its output power spectrum, and then we use this device to drive the transom qubit in a special setup shown in Fig. 1. In this experiment we perform a standard two-tone qubit spectroscopy using either a conventional room-temperature based microwave generator or a cryogenic on-chip Josephson junction-based source. The change in the S_{21} parameter indicates that the qubit has transitioned to an excited state when exposed to a Josephson radiation (Fig. 1e).

We also experimentally study other types of cryogenic microwave sources based on long Josephson junctions (LJJ) [5-7]. The resonant excitations in these systems can also be used to reduce the radiation bandwidth. We present a novel design of an LJJ based on a spiral geometry that can help increase the overall compactness of an on-chip device.

Acknowledgment: This research was supported by RSF grant #24-19-00187.

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Superferromagnetoresistors

V. N. Kondratyev[1,2,*], V. A. Osipov [1]

[1] *Bogolubov Laboratory of Theoretical Physics, JINR, 141980, Dubna, Russia*
[2] *Dubna State University, 141980, University str., 19, Dubna, Russian Federation*

Corresponding Author: V. N. Kondratyev
Email: vkondrat@jinr.ru

Spintronic magnetoresistive sensors (MRS) based on micro- and nano-devises are widely used in recording and non-recording devices. High sensitivity of such MRS meets the requirements of intelligent sensor applications in many areas, e.g., healthcare and medicine, mobile devices, internet, space technology, aeronautics, magnetic flux leakage, domotics, and environment. Besides, the spread applications and production of such MRS are ensured by their adaptability and miniaturization, simple integration, and cost-effectiveness.

In this work, we investigate ensembles of superparamagnetic particles (SPM). At sufficiently large SPM densities, these metamaterials show superferromagnetic properties and can be used as MRS, cf., e.g., [1] and refs. therein. We show that the tunneling MR per atom increases as the size of the SPM decreases, see Fig.1. The effect of giant magnetoresistance (GMR) is determined by the ratio of the time of flight between SPMs and the relaxation time. The MR signal can reach tens of percent already at room temperature.

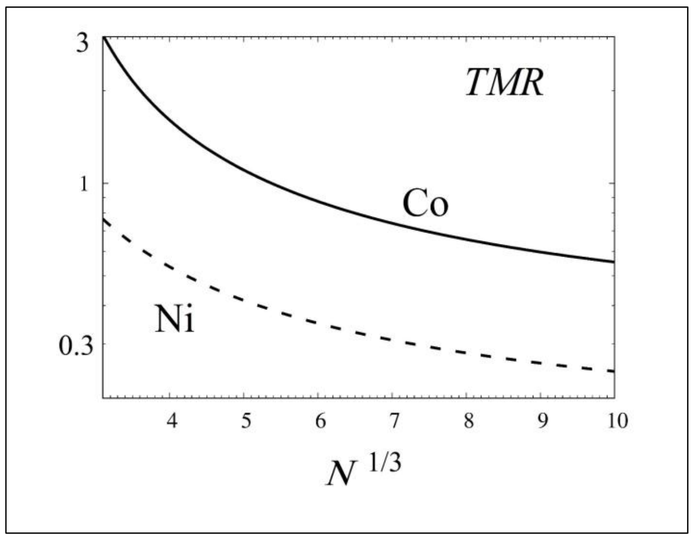

Fig. 1. Tunnel MR per atom dependence on the number of atoms N in SPM for Ni – dashed line and Co – solid line.

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Effects of the in-plane magnetic field in van der Waals bilayers with interlayer superconducting ordering

A. A. Kopasov [1], D.S. Annenkov [2], A. S. Mel'nikov [2,3]

[1]National University of Science and Technology "MISIS", Moscow 119049, Russia
[2]Moscow Institute of Physics and Technology (National Research University), Dolgoprudnyi, 141701 Moscow Region, Russia
[3]Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105 Russia

Corresponding Author: A. A. Kopasov
Email: kopasov.aa@misis.ru

Recent interest to the interlayer pairing mechanism [1,2] is related with the progress in the study of superconductivity in van der Waals heterostructures [3,4]. These structures provide a new possibility for engineering the superconducting state due to the fact that their band structure can be controlled by an external electric field.

This work studies the influence of the in-plane magnetic field on possible interlayer superconducting ordering. An important property of such pairing is that due to the nonlocality of the Cooper pair wave function the Pauli principle does no more impose severe restrictions on spins of electrons in the pair, which usually hamper the formation of the spin-triplet superconducting correlations. Based on the formalism of quasiclassical Eilenberger equations for a model two-dimensional bilayer system [5] we carry out an extensive analysis of the superconducting phase diagram. It is shown that the influence of orbital and paramagnetic mechanisms is sensitive to the spin-structure of interlayer Cooper pairs. We find that the suppression of spin-singlet interlayer superconductivity due to the orbital effect is governed by the relation between the relative energy band shift and the tunneling amplitude. On the contrary, the orbital effect can result in the enhancement of the interlayer spin-triplet superconductivity. The paramagnetic effect can lead to the in-plane anisotropy of the depairing for spin-triplet pairs as well as to the appearance of reentrant superconducting phases [6] for both spin-singlet and spin-triplet interlayer pairing. The obtained results are discussed in the context of recent experiments on coexistence of ferroelectricity and superconductivity in van der Waals bilayers [7,8].

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Current steps in voltage-biased φ_0 Josephson junction under a harmonic magnetic field

E. S. Kovalenko[1]

[1]*Center for the Development of Digital Technologies, Krasnogorsk, 143401, Russia*

Corresponding Author: E. S. Kovalenko

Email: valinbox@gmail.com

The effects of mutual influence of superconductivity and magnetism are currently being actively studied and have great potential for application in superconducting electronics of the future [1]. In [2], it was shown that in the Josephson superconductor-ferromagnet-superconductor junction with a strong spin-orbit interaction in the ferromagnet, a connection arises between the superconducting phase and the magnetic moment.

In this work, the influence of an external harmonic magnetic field on the precession of magnetization and on the current-voltage characteristic of voltage-biased φ_0 junction near ferromagnetic resonance is analytically studied.

At a certain ratio of the frequency of Josephson oscillations to the frequency of the external magnetic field, phase synchronization of these oscillations occurs. This leads to the appearance of a constant term in the supercurrent, which manifests itself as a current step on the current-voltage characteristic. This is the so-called Buzdin step, first obtained in [3] by numerical methods for current-biased φ_0 junction.

The ratio of frequencies defining the position of interger and half-integer Buzdin steps is established. The obtained expression for the width of the Buzdin step shows how the width of the step depends on the strength of the spin-orbit interaction, on the proximity to ferromagnetic resonance, on the frequency and amplitude of the magnetic field.

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Josephson emission: junction as an active antenna

Vladimir M. Krasnov.

Department of Physics, Stockholm University, AlbaNova University Center, 10691 Stockholm, Sweden

Corresponding Author: V. Krasnov

Email: Vladimir.krasnov@fysik.su.se

Josephson oscillators show a remarkable performance in terms of tunability and linewidth. However, they emit very little power into free space. The low radiation power efficiency, that is, the ratio of radiated to dissipated power, is commonly attributed to a large impedance mismatch between a Josephson junction (JJ) and free space. But there is no consensus about the value of the junction impedance: Is it very small or, in contrast, very large? At present, there is no clear understanding about what causes the impedance mismatch and which geometrical parameters should be changed for solving the problem. The discovery of significant terahertz emission from stacked intrinsic JJs in layered high-T_c cuprates further emphasizes the necessity of a quantitative understanding of microwave emission from Josephson oscillators.

Optimization of Josephson oscillators requires a quantitative understanding of their microwave properties. A Josephson junction has a geometry similar to a microstrip patch antenna. However, it is biased by a dc-current, distributed over the whole area of the junction. The oscillating electric field is generated internally via the ac-Josephson effect. In this talk I present a distributed, active patch antenna model of a Josephson oscillator. It takes into account the internal Josephson electrodynamics and allows determination of the effective input resistance, which couples Josephson current to cavity modes in the transmission line formed by the junction. The model provides full characterization of Josephson oscillators and explains the origin of low radiative power efficiency. Finally, I discuss the design of an optimized Josephson patch oscillator, capable of reaching high efficiency and radiation power for emission into free space.

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Observation of the Leggett collective plasma oscillation and the spin exciton in two-gap superconductors using SNS-Andreev spectroscopy

S.A. Kuzmichev[1,2], T.E. Kuzmicheva[2], M. M. Korshunov[3], B. M. Bulychev[4], S. I. Krasnosvobodtsev[2], N. D. Zhigadlo[5], I.V. Morozov[4]

[1] *Faculty of Physics, M.V. Lomonosov Moscow State University, 1, Leninskiye Gory 119991, Moscow, Russia*
[2] *P.N. Lebedev Physical Institute of the RAS, 53, Leninsky Ave., 119991 Moscow, Russia*
[3] *L.V. Kirensky Institute of Physics, SB RAS, 60, Akademgorodok, 660036, Krasnoyarsk, Russia*
[4] *Department of Chemistry, Moscow State University, 1, Leninskiye Gory 119991, Moscow Russia*
[5] *Crystmat company, 11 Zschokkestrasse, 8037 Zuric, Switzerland*

Corresponding Author: S. A. Kuzmichev

Email: kuzmichev@lt.phys.msu.ru

MgB_2 becomes the first-ever-known two-gap SC, where two weakly interacting SC condensates with the distinct coupling energies ($2\square_{\square}$ and $2\square_{\square}$) develop in the SC state below T_c. As early as in 1966 A.J. Leggett predicted that collective plasma oscillation caused by small fluctuations of the phase difference between two SC condensates (“internal Josephson effect in the k-space”), develop in two-gap superconductors [1]. The main result of the pioneer work [1] re-derived by Sharapov *et al*. [2] specially for MgB_2 is that the square of the massless term of the oscillation frequency $\square_0^2 = \square_L^2(k \rightarrow 0)$ at T = 0 is proportional to $\square_{\square}(0)\cdot\square_{\square}(0)$. For the first time, Leggett plasmon in MgB_2 was experimentally detected in our laboratory by supervision of Prof. Ya.G. Ponomarev in 2002 [3,4].

For the iron-based superconductors, the Fermi surface consists of hole barrels near the □ point and electron barrels near the M point of the Brillouin zone, which are coupled by a nesting vector **Q**. As a result, within the framework of 5-orbital $s^{\pm}$-model, the imaginary part of the dynamic spin susceptibility Im[$\square(\mathbf{Q},\square)$] shows a spin-resonance peak at position $\square_R(0) < [\square_L(0) + \square_S(0)]$ [5].

At 4.2 K, using a planar ``break-junction'' technique we formed Josephson SIS and Andreev SnS nanojunctions (S is superconductor, n — thin normal metal, I — insulator). In I(V) and dI(V)/dV characteristics of the tunneling junctions, we reproducibly observed a fine structure caused by a resonant interaction of Josephson supercurrent with a bosonic mode (in SIS regime) or emission of bosons during multiple Andreev reflections (in SnS regime), and determined the energy of the bosonic mode [6].

Here we revisit our experimental results on Leggett plasma mode detection in disordered MgB_2 and electron doped (Mg,Al)B_2 compounds in a wide range of critical temperatures $T_c \approx 13.5$–40 K. In average, $\square_0$ does not exceed the small SC gap $2\square_p(0)$ value and reaches $\square_0 \approx 4$–5 meV in MgB_2 with $T_c \approx 40$ K. Summarizing the data obtained by Josephson and Andreev spectroscopies, we demonstrate almost linear $\square_0^2(\square_{\square}\cdot\square_{\square})$ dependence within this T_c range [3,4] and present here an experimental temperature dependence of the Leggett plasma mode $\square_0(T)$.

In the dI(V)/dV-spectra of SnS-junctions formed in Gd(O,F)FeAs and (Sm,Th)OFeAs oxypnictides (the 1111 family) with various doping degree and maximum $T_c \approx 50$ K [7–10], as well as in $(K,Na)_xFe_{2-y}Se_2$ selenides with $T_c \approx 26$ K, the observed fine structure was attributed to an interaction with a spin exciton. In particular, multiple emission of up to 4 bosons was detected in (Sm,Th)OFeAs [9]. At $T << T_c$, the spin exciton energy $\square_0$ was not exceed the indirect SC gap $\square_L(0) + \square_S(0)$ in the oxypnictides, and $2\square(0)$ in single-gap selenides. In the 1111-compounds, under doping variation, $\square_0$ was scaled with T_c together with $\square_L(0)$ and $\square_S(0)$ [7,9].

The experimental temperature dependence $\square_0(T)$ agrees well with the $\square_R(T)$ dependence calculated within the $s^{\pm}$ model [10].

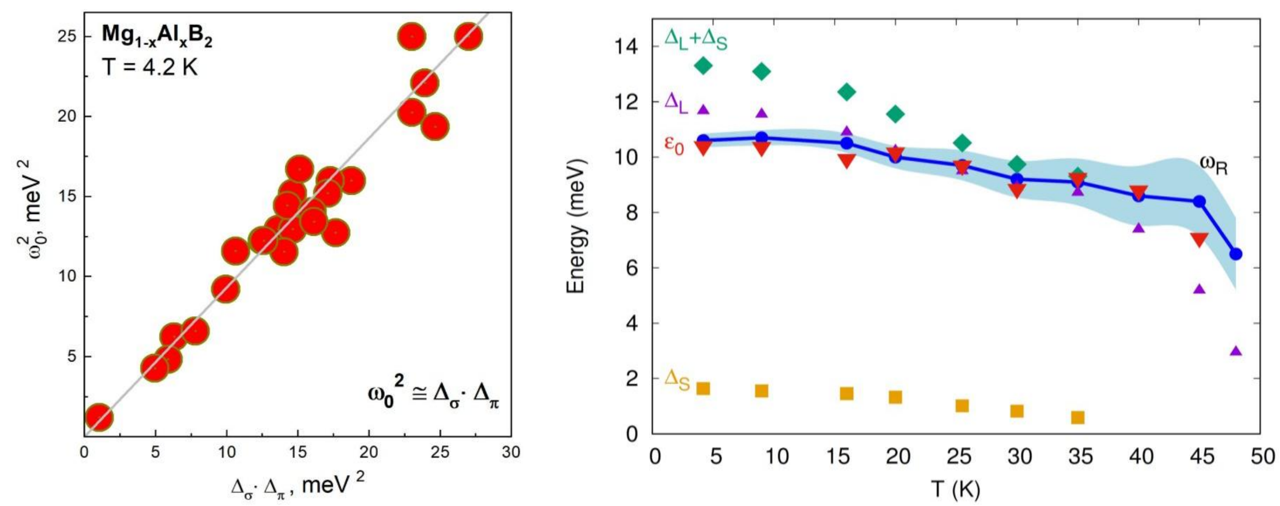

Fig. 1. Experimental check of the Leggett expression for the two-gap SC: the Leggett's mode frequency $\square_0$ squared versus SC gaps product at $T << T_c$ in $(Mg,Al)B_2$ (left panel). Experimental data — sum of large and small SC gaps (diamonds), large SC gap $\square_L$ on T (up triangles), small SC gap $\square_S$ on T (squares), the spin exciton energy $\square_0$ (down triangles); theory — spin-resonance peak position $\square_R(T)$ (connected circles) in Gd(O,F)FeAs compound (right panel).

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Single-gap superconductivity of alkali-metal ferroselenides with isovalent substitution

T.E. Kuzmicheva[1], S.A. Kuzmichev[2,1], A.D. Ilina[1], I.A. Nikitchenkov[2,1], A.I. Shilov[1], E.O. Rakhmanov[3,1], I.V. Morozov[3]

[1] *P.N. Lebedev Physical Institute of the RAS, 53, Leninsky Ave., 119991 Moscow, Russia*
[2] *Faculty of Physics, M.V. Lomonosov Moscow State University, 1, Leninskiye Gory 119991, Moscow, Russia*
[3] *Department of Chemistry, Moscow State University, 1, Leninskiye Gory 119991, Moscow Russia*

Corresponding Author: T. E. Kuzmicheva

Email: kuzmichevate@lebedev.ru

Selenides $A_xFe_{2-y}Se_2$ (A — Na, K, Rb, the so-called 122-Se family) are natural composites containing at least two coexisting phases: about 80% of the volume is occupied by crystals of the AFM dielectric phase $A_{0.8}Fe_{1.6}Se_2$, and about 20% — by crystallites of the metallic $A_{0.3}Fe_2Se_2$ phase which becomes superconducting below T_c. It is known that different types of isovalent substitution differently affect the critical temperature T_c: thus, even a small substitution of an alkali metal causes a jump-like T_c change [1], while under (Se,S) substitution, T_c forms a ``semi-dome'' [2]. Due to natural phase separation and rapid degradation of the SC properties in open air (in several minutes), $A_xFe_{2-y}Se_2$ selenides remain extremely understudied to date.

In particular, for the compositions considered in the work, $K_{0.8}Na_{0.2})_{0.9}Fe_{1.7}Se_2$ (hereafter KNFS), $(K_{0.3}Na_{0.3}Rb_{0.3})_{0.8}Fe_{1.7}Se_2$ (NKRFS), and $K_{0.8}Fe_{1.7}(Se_{0.73}S_{0.27})_2$ (KFSS), the topology of the Fermi surface remains unknown, and there are also no data from other groups on the amount of SC condensates formed below T_c.

Using the "self-flux" method, we grew large (up to 8–10 mm) KNFS, KFSS, and NKRFS crystals with three types of isovalent substitution and the range of critical temperatures $T_c \approx 25$–34 K [3–5]. Using the planar mechanically controlled "break-junction" technique [6], various types of tunnel structures were created in the crystals, including Andreev SnS contacts and tunneling ScS contacts (where *S* is a superconductor, *c* — constriction, and *n* — thin normal metal).

Using IMARE spectroscopy of SnS-junctions, the magnitude of the SC gap and its BCS-like temperature dependence were directly determined. We show a bulk nature of the detected SC gap, the reproducibility of its magnitude, and independence on the geometric parameters of the SnS-contact (i.e., area and the normal resistance).

The obtained temperature dependences of the excess Andreev current $I_{exc}(T) \equiv I(T, eV) - I(T_c, eV) \propto \Delta(T)$, taken at a constant bias $eV >> 2\Delta$, are well described by a single-band BCS-shaped dependence, which agrees with the theoretical predictions [7] for the IMARE regime. Using tunnel spectroscopy of ScS contacts, the temperature dependence of the supercurrent $I_c(T)$ was obtained, that could be roughly related to the Cooper pairs concentration. The experimental data [4] can be fitted with the Cooper pair concentration $n_S(T) = \Delta(T)\cdot\tanh[\Delta(T)/2k_BT]$ using the experimental $\Delta(T)$ dependence directly measured by IMARE spectroscopy.

The data obtained by three methods (□(T), I_{exc}(T), I_c(T)) indicate the consistency of the results of the used spectroscopic techniques and unambiguously indicate the implementation of single-gap superconductivity of the studied ferroselenides.

In KNFS and KFSS, the characteristic ratio was 2□(0)/$k_BT_c \approx 4.1$–4.6, whereas in NKRFS this value was a bit larger: 2□(0)/$k_BT_c \approx 4.4$–5.0. All the values exceed the weak-coupling BCS-limit 3.5, thus indicating strong coupling in the electron bands.

The similarity of the SC-gap structure and the value of the characteristic ratio allows us to conclude a similar mechanism of Cooper pairing realized in KNFS and KFSS. The observed constancy of the 2□(0)/k_BT^c characteristic ratio, i.e., scaling between 2□(0) and T_c indicates a single evolution of the properties of the SC subsystem of KNFS and KFSS selenides with a critical temperature. Contrary, a minor strengthening of the Cooper pairing in the ternary NKRFS compound develops, as compared to ferroselenides with (Na,K) and (Se,S) isovalent substitution.

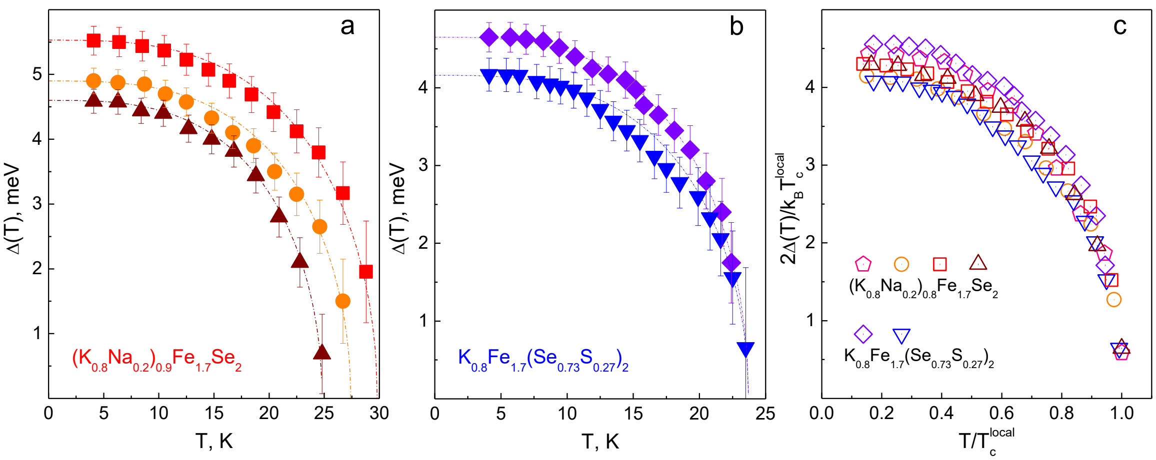

Fig. 1. Directly measured temperature dependence of the single SC gap in KNFS (a) and KFSS (b). The same data in normalized terms 2□(T)/k_BT_c vs. T/T_c are presented in (c).

Acknowledgment: The work is supported by RFS project no. 22-72-10082

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Peculiarities of the vortex dynamics in a granular niobium superconducting bridge

S. A. Larionov [1,2], D. Yu. Vodolazov [1,4], D. Roditchev [3], A. G. Shishkin [1,2], V. S. Stolyarov [1,2,3]

[1]*Advanced Mesoscience and Nanotechnology Centre, Moscow Institute of Physics and Technology, Dolgoprudny 141700, Russia*
[2]*All-Russian Research Institute of Automatics n.a. N.L. Dukhov (VNIIA), 127030, Moscow, Russia*
[3]*LPEM, UMR-8213, ESPCI Paris, PSL, CNRS, Sorbonne University, 75005 Paris, France*
[4]*Institute for Physics of Microstructures, Russian Academy of Sciences, 603950, Nizhny Novgorod, GSP-105, Russia*

Corresponding Author: S. A. Larionov

Email: larionov.sa@phystech.edu

The voltage-current characteristics *V(I)* of submicron-wide superconducting bridges fabricated from granular niobium films reveal unexpected regions of negative differential resistance (NDR), where $\partial V/\partial I<0$. Magnetic Force Microscopy (MFM) measurements indicate that above the critical current, the observed voltage arises from the motion of quantum vortices along the weakest intergranular links, which form a nanoscale conduction network. The simulations based on the time-dependent Ginzburg–Landau (TDGL) model support these findings, showing that vortex–vortex interactions within such a granular network can significantly reduce the overall vortex velocity. This collective effect results in the flattening of the V(I) curve and the emergence of NDR regions.

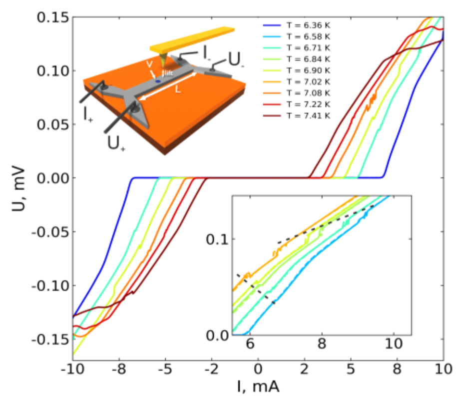

Fig. 1. Experimental setup and electron transport measurements

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Magnetic moment bifurcation on different synchronized voltage steps in φ_0 Josephson junction

M. Nashaat[1,2], E. Kovalenko[3], Yu. M. Shukrinov[1,4]

[1] BLTP, JINR, Dubna, Moscow region, 141980, Russia
[2]Department of Physics, Faculty of Science, Cairo University, 12613, Egypt
[3]Center for the Development of Digital Technologies, Krasnogorsk, Russia
[4]Dubna State University, Dubna, 141980, Russia

Corresponding Author: M. Nashaat

Email: majed@sci.cu.edu.eg

Superconductor-ferromagnet-superconductor φ_0 Josephson junctions under the presence of external electromagnetic radiation have been studied. We demonstrate the implementation of different types of dynamical states of magnetization on the Buzdin and chimera steps[1,2,3]. These states in the synchronization region are distinguished by the type of magnetic moment precession and their Josephson oscillations have phase difference of π [3]. The possibility of switching between these states using a current pulse is demonstrated. Transitions between these states with increasing and decreasing bias current show hysteresis, which is reflected in the bifurcation diagram and the current-voltage characteristics. Additionally, we demonstrate how the results can be verified experimentally by measuring the phase shift in voltage temporal dependence at fixed current values in both directions. Various applications of the results obtained can be found in the field of superconducting spintronics and quantum computing.

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Interplay of superconductivity and altermagnetism in hybrid systems

M. M. Vasiakin[1,2], A. S. Melnikov[2,3]

[1] L. D. Landau Institute for Theoretical Physics RAS, 142432 Chernogolovka, Russia;
[2]Moscow Institute of Physics and Technology, Dolgoprudnyi, Moscow region, 141701 Russia;
[3] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, Russia

Corresponding Author: A. S. Melnikov

Email: melnikov@ipm.sci-nnov.ru

Starting from the microscopic Gor'kov theory, we study the effect of normal scattering on superconducting phase transition in superconductor-altermagnet bilayers. Scattering on non-magnetic point impurities is shown to result in a strong enhancement of superconducting critical temperature (Tc) due to the averaging of momentum-dependent exchange field induced by the altermagnetic layer. The inclusion of magnetic scattering may lead to the non-monotonic behavior of Tc. Moreover, in "dirty" limit, the effect of the altermagnetic exchange field can be reduced to effective magnetic impurities. The origin of these phenomena is shown to be related to the Dyakonov-Perel mechanism of spin relaxation. Similar phenomena of superconducting Tc enhancement reveal themselves for superconductivity nucleation near different boundaries and sample edges. We analyze, in particular, the mechanism of stimulation of the edge superconductivity due to the scattering of quasiparticles at the edge, which partially suppresses the depairing effect of the exchange field.

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Superconductor-ferromagnet spin valve with tunable inductance

A.A. Neilo[1], S.V. Bakursky[3,4], N.V. Klenov [1,3], I.I. Soloviev[2,4], M.Yu. Kupriyanov [3,4]

[1]Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia, 119234
[2]Dukhov All-Russian Research Institute of Automation, Moscow, Russia, 127055
[3]NIIPh MSU, Leninskie Gory, Moscow, Russia, 119234
[4]National University of Science and Technology MISIS, Moscow, Russia, 119049

Corresponding Author: A. A. Neilo

Email: aleks.neilo@yandex.ru

One of the primary objectives of superconducting electronics is the development of low-dissipation and energy-independent memory and control elements. These elements can facilitate the design of supercomputers, data centers, neuromorphic circuits, and quantum computers. The utilization of hybrid structures comprising superconductors (S) and ferromagnets (F) represents a contemporary and promising avenue of advancement in the field of device development. The incorporation of a low-resistance normal metal into the structure enables the regulation of considerable kinetic inductance [4–5]. The interaction of superconducting and ferromagnetic orders in SF structures can give rise to a number of distinctive effects, which in turn offer the potential for the creation of superconducting spin valves (SSV).

In this work, we examine the chain effect in a SFsFs(N)-type superconducting spin valve comprising a substantial superconducting electrode (S), an FsF spin valve, and a thin superconducting film on which a low-resistance (N) normal metal was situated. The Uzadeli measurement demonstrated that the mutual change in the orientation of the magnetization vectors of the F-layers from parallel to antiparallel allows a significant increase in superconductivity even in a thin s-film. The alteration in the pairing capacity of the external film was examined, and the parameters that contribute to the spin valve effect were identified. The most pronounced effect is observed in the region of parameters where the pairing capacity assumes opposing signs in the parallel state. Conversely, the incorporation of a low-normal metal markedly alters the change in the kinetic inductance of the entire structure. This study presents novel avenues for the development of devices with readily adjustable inductance and superior quality.

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Detectors for radioastronomy and axion search

A.L. Pankratov[1,2], D.A. Ladeynov[1], D.A. Pimanov[1], L.S. Revin[1,2], A.V. Chiginev[1,2], A.V. Gordeeva[1], A.V. Blagodatkin[1]

[1] Nizhny Novgorod State Technical University n.a. R. E. Alekseev, Nizhny Novgorod, 603950, Russia
[2] Institute for Physics of Microstructures of RAS, Nizhny Novgorod, 603950, Russia

Corresponding Author: A. L. Pankratov

Email: alp@ipmras.ru

The current progress in the field of microwave single photon detectors in the frequency range of 5-15 GHz will be presented [1,2]. A prototype of a single microwave photon counter based on an aluminum SIS junction has been designed, manufactured, and investigated. Both large and small Josephson junctions (JJs) were investigated in the temperature range from 15 mK to 1 K [3]. Summarizing the obtained data, it is shown that the transition temperature between the running state and the phase diffusion regime scales exponentially as a function of kT/hf for JJ critical currents from 70 to 1000 nA. In addition, the quantum crossover temperature decreases with decreasing critical current. At the same time, it is shown that the "quantum floor" below the quantum crossover temperature is not constant, but has a finite slope proportional to the temperature as hf+kT, due to residual thermal activation switching against the background of dominant tunneling under a barrier. The achieved dark count rates, reaching 0.01 Hz, turned out to be much lower than expected from previously existing theories due to the operation of the JJ in the phase diffusion regime [1-3]. To test the detection efficiency, classical sources of microwave photons are used: a synthesizer that provides Poisson photon statistics and a heated microwave resonator, which is a source of thermal 9 GHz and 14 GHz photons. The detection efficiency of thermal photons reaches 45% with super-Poisson statistics, confirming their nature [2], which is also the direct observation of quantum chaos.

The results of the development and study of receivers with cold-electron bolometers [4,5] for radio astronomy and dark matter search are presented. Such detectors combine important advantages: electron cooling and record radiation immunity, which allows their use in space. In addition, such detectors can be used to search for galactic axions using broadband dish antennas in strong magnetic fields in the frequency range of 0.1-1 THz. The advantage of both types of experiments for the search for axions in strong magnetic fields is the possibility of conducting research without the use of expensive low-background laboratories.

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Submicron Nb/Al/Nb Josephson junction for superconducting circuits

K.B. Polevoy[1, 2,*], S. V. Bakurskiy[1,2,3], V. I. Ruzhickiy[1,2,3], A. G. Shishkin[1, 2], V. S. Stolyarov[1, 2]

[1] Moscow Institute of Physics and Technology, 141700, Russia
[2] All-Russian Research Institute of Automatics n.a. N.L. Dukhov (VNIIA), 127030, Russia
[3] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Russia

Corresponding Author: K. B. Polevoy

Email: polevoy.kb@phystech.edu

We report on the successful fabrication and detailed characterization of submicron planar Nb/Al/Nb Josephson junctions with an active area of 5×10^4 nm². Our findings indicate that aluminum, employed as a weak link material, markedly increases the critical current across all temperatures due to the proximity effect. When cooled to 4.2 K, the junction demonstrates non-hysteretic current-voltage behavior, making it a strong contender for applications in superconducting digital electronics. The device achieves characteristic voltages of up to 7 mV and critical currents around 50 μA.

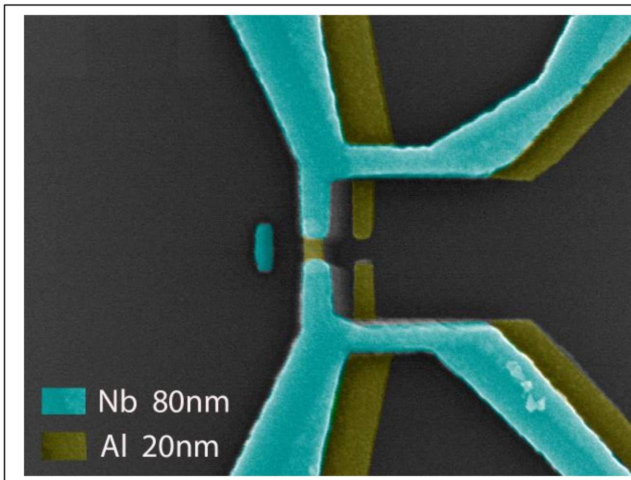

Fig. 1. SEM image of one of the studied junctions. Al layer painted as green, Nb layer painted as blue.

Vortex structure and intervortex interaction in superconducting structures with intrinsic diode effect

A. V. Putilov[1], D. V. Zakharov[2], A. Kudlis[3], A. S. Mel'nikov[1,4], A. I. Buzdin[5]

[1]*Moscow Institute of Physics and Technology, Dolgoprudnyi, Moscow Region 141701, Russia*
[2]*ITMO University, Saint-Petersburg, Kronverksky Pr. 49, bldg. A, St. Petersburg, 197101, Russia*
[3]*Science Institute, University of Iceland, Dunhagi 3, IS-107 Reykjavik, Iceland*
[4]*Institute for Physics of Microstructures RAS, 603950 Nizhny Novgorod, GSP-105, Russia*
[5]*University of Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France*

Corresponding Author: A. V. Putilov

Email: alputilov@ipmras.ru

We consider a thin superconducting (S) film deposited on an insulating ferromagnet (F) within the modified Ginzburg-Landau functional. The magnetochiral anisotropy triggered by the exchange field and the interfacial spin-orbit interaction (SOI) can be incorporated into the GL free-energy density through the odd spatial-derivative terms whose strength is set by two phenomenological constants ε_1 and ε_3. The interface normal **n** breaks inversion symmetry, while an in-plane exchange field **h** breaks time-reversal symmetry; taking **h** parallel to the layers suppresses stray fields. The vectors **n** and **h** together single out the in-plane direction $[\mathbf{n} \times \mathbf{h}]$ that governs all non-reciprocal responses. Since the SOI is confined to an atomic-scale interface layer, its effects are more pronounced if the film thickness d is of the order of coherence length ξ. In this limit, variations of the order parameter along **n** can be neglected, which leads to the two-dimensional density of free energy

$$U = -\alpha|\psi|^2 + 0.5\beta|\psi|^4 + \xi^2\alpha|\mathbf{D}\psi|^2 + (\varepsilon_1\, \psi^*[\mathbf{n} \times \mathbf{h}]\mathbf{D}\psi + \varepsilon_3\, \mathbf{D}\psi^*[\mathbf{n} \times \mathbf{h}]\mathbf{D}^2\psi + c.c.),$$

where operator $\mathbf{D} = -i\nabla - 2\pi\mathbf{A}/\Phi_0$ where **A** is a vector potential.

Within this modified GL functional, we demonstrate that the intrinsic superconducting-diode effect can strongly reshape Abrikosov vortices and leads to a chiral distortion of the superfluid velocity, non-central interaction forces and resulting torque in a vortex-antivortex pair, and anisotropy of the Bean-Livingston barrier. These closed-form results are fully confirmed by time-dependent GL numerical simulations carried out with a fourth-order least-squares finite-difference solver, which captures equilibrium single vortex configuration in realistic mesoscopic geometries. The analysis shows that the cubic gradient term shifts vortex cores by an amount proportional to the in-plane exchange field and simultaneously generates a lateral torque that can rotate entire vortex ensembles, showing how spin-orbit coupling (SOC) and the exchange field enable breakdown of the vortex–antivortex symmetry in a finite-size sample.

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Magnetotransport of Pb/$Bi_{1.08}Sn_{0.02}Sb_{0.9}Te_2S$ heterostructures

V.O. Sakhin, E.F. Kukovitsky, A.A. Kamashev, N.N. Garifyanov, Yu. I. Talanov

Zavoisky Physical-Technical Institute, FRC Kazan Scientific Center of RAS, Russia

Corresponding Author: V. O. Sakhin

Email: vsakhin@yahoo.com

Superconductor/topological insulator (TI) heterostructure is a promising platform for realizing exotic quantum phenomena. Topological insulators are known for the nontrivial properties of their conducting surface. When such material is brought into contact with a superconductor, the proximity effect can induce superconductivity on the interface, potentially giving rise to topological superconductivity—a phenomenon of significant interest for the development of Majorana-based qubits in quantum computing [1,2].

As an initial step toward creating such a system, we fabricated a heterostructure using a TI with a low bulk carrier concentration [3], which leads to transport being dominated by surface states at lower temperatures even in the case of sample of macroscopic scale. The material selected, $Bi_{1.08}Sn_{0.02}Sb_{0.9}Te_2S$, is a bismuth chalcogenide known for its layered structure, which allows mechanical cleavage along the crystallographic *ab* plane. Thin films of Pb were deposited onto the TI surface using molecular beam epitaxy. Lead was chosen for its relatively high critical temperature (T_C = 7.2 K), strong adhesion to the TI surface, and it has previously been used in heterostructure fabrication based on TI [4,5]. At thicknesses below 20 nm, the Pb layer becomes discontinuous [6], allowing superconducting current to partially flow through the TI surface. Importantly, this does not significantly reduce the superconducting transition temperature.

The study focuses on measuring the magnetoresistance of the Pb/$Bi_{1.08}Sn_{0.02}Sb_{0.9}Te_2S$ heterostructure and investigating critical parameters (such as T_C and I_C) behavior. The temperature dependence of the critical magnetic field (H_C) may provide insight into the nature of the interfacial superconductivity. In structures with thin, non-uniform Pb layers, the observed magnetoresistance reflects a combination of contributions from both the superconductor and the TI, including weak antilocalization.

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Quantum Coulomb drag mediated by cotunneling of fluxons

Andrew G. Semenov [1], Alex Latyshev [2], Andrei D. Zaikin [13]

[1]I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, Russia
[2]Departement de Physique Theorique, Universite de Geneve, CH-1211 Geneve 4, Switzerland
[3]National Research University Higher School of Economics, 101000 Moscow, Russia

Corresponding Author: A. G. Semenov

Email: semenovag@lebedev.ru

We predict novel quantum drag effects that can occur in macroscopically quantum-coherent Josephson circuits. We demonstrate that biasing one resistively shunted Josephson junction by an external current one can induce a non-zero voltage drop across another such junction capacitively coupled to the first one. This quantum Coulomb drag is caused by cotunneling of magnetic flux quanta across both junctions which remain in the "superconducting" regime. In particular we investigate this phenomenon in a system of two small Josephson junctions coupled by means of mutual capacitance C_m. Depending on the value of C_m we identify three different regimes of strong, intermediate and weak coupling. By means of different versions of instanton technique we explicitly derive fluxon cotunneling amplitudes for all three regimes. We demonstrate that the Coulomb drag effect survives at any non-zero C_m and evaluate the non-local voltage response that is in general determined by a tradeoff between two different cotunneling processes. Our predictions can be straightforwardly generalized to bilinear Josephson chains and directly verified in future experiments.

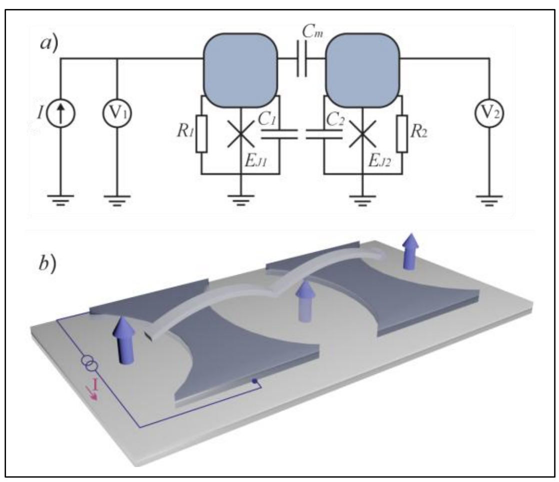

Fig. 1. a) The system under consideration. b) Schematic representation of fluxon cotunneling in a system of coupled Josephson junctions.

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Peculiarities of the mutual influence of superconductivity and magnetism in Josephson structures with ferromagnet

Yu. M. Shukrinov[1,2]

[1] *JINR, Dubna, Russia*
[2] *Dubna University, Dubna, Russia*

Corresponding Author: Yu. M. Shukrinov
Email: shukrinv@theor.jinr.ru

The short review on the effects of mutual influence of superconductivity and magnetism in the Josephson $\boldsymbol{\varphi}_0$ junction with a direct coupling of the Josephson phase and magnetization is presented [1]. The interesting prospects in the field of superconducting spintronics, in particular, based on the reversal of the magnetic moment by a superconducting current, the manifestation of the Kapitsa pendulum features by the $\boldsymbol{\varphi}_0$ junction are discussed [2]. The results of studies of the dynamics and current-voltage characteristics (CVC) of the junction under the action of external electromagnetic radiation are presented [3-5]. A new element in the consideration of this problem is the inclusion of the magnetic component of the radiation, which leads to the emergence of new synchronization mechanisms and corresponding steps on the CVC. We discuss the resonant control of magnetization in a shunted $\boldsymbol{\varphi}_0$ junction with LC circuit, the locking, hysteresis, and chaotic features [6-8]. The combination of Josephson and Kittel ferromagnetic resonances in the $\boldsymbol{\varphi}_0$ junction with different types of synchronization, clearly expressed in the dynamics and in the CVC, makes the physics of this system very interesting and opens up a number of new applications.

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The fate of Majorana zero modes under Markovian dissipation

M.S. Shustin[1], S.V. Aksenov[1], I.S. Burmistrov[1,2]

[1] L.D. Landau Institute for Theoretical Physics, acad. Semenova av.1-a, Chernogolovka 142432, Russia
[2]Laboratory for Condensed Matter Physics, HSE University, Moscow, 101000, Russia

Corresponding Author: M. Shustin

Email: mshustin@yandex.ru

We study the spectral properties of topological superconductors (TS) affected by dissipation and in the presence of coupling to the equilibrium reservoirs. The evolution of the density matrix of the system is modeled in the framework of the Gorini-Kossakowski-Sudarshan-Lindblad equation [1,2], in which the unitary evolution of TS is described by Hamiltonian, which is quadratic in fermionic operators, while jump operators are linear in fermionic operators (linear dissipative fields). To analyze the system, we use the third quantization method with the introduction of the Fock-Liouville operator space [3]. The main goal of our study is to analyze the evolution of Majorana zero modes (MM) of topological superconductors [4] when exposed to linear dissipative fields. In contrast to recent studies [5-7], we study the most general formulation of the problem: an arbitrary TS Hamiltonian hosting several Majorana modes and arbitrary linear dissipative fields. We demonstrate that the MMs in the isolated TS are transformed into the so-called zero kinetic modes ZKM in the presence of dissipation and coupling to reservoirs. Importantly, the number of ZKM (N_0) is smaller than the number of MM ($2N_M$) in the isolated TS. We prove that $N_0 = 2N_M - \mathrm{rk}\,\mathcal{B}$ where the cross-Gramian matrix $\mathcal{B} \in \mathbb{R}^{2N_M \times 2(N_B+N_R)}$, describes the hybridization of $2N_M$ MM wave functions of the isolated TS with $2N_B$ dissipative fields and $2N_R$ reservoirs. It is worthwhile to mention that depending on the rank of the matrix $\mathcal{B}$ the number of ZKM may be odd. Based on knowledge of hybridization matrix $\mathcal{B}$, we propose practical recipes that allow manipulating the number of NESS in dissipative TS. We apply our general results to the generalized Kitaev chain [8] with long-range hoppings and superconducting pairings, where MM localized at the edges can be explicitly constructed.

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Thermal phase slips in superconducting films

Mikhail A. Skvortsov, Artem V. Polkin

L. D. Landau Institute for Theoretical Physics, Chernogolovka 142432, Russia

Corresponding Author: M. A. Skvortsov

Email: skvor@itp.ac.ru

A dissipationless supercurrent state in superconductors can be destroyed by thermal fluctuations. Thermally activated phase slips provide a finite resistance of the sample and are also responsible for dark counts in superconducting single photon detectors. The activation barrier for a phase slip is determined by a space-dependent saddle-point (instanton) configuration of the order parameter. In the one-dimensional wire geometry, such a saddle point has been analytically obtained by Langer and Ambegaokar [1] in the vicinity of the critical temperature, T_c, and for arbitrary bias currents below the critical current I_c. In the two-dimensional geometry of a superconducting strip, which is relevant for photon detection, the situation becomes much more complicated. Depending on the ratio I/I_c, several types of saddle-point configurations have been proposed, with their energies being obtained numerically. We demonstrate that the saddle-point configuration for an infinite superconducting film at $I \to I_c$ is described by the exactly integrable Boussinesq equation solved by Hirota's method. The instanton size is $L_x \sim \xi(1 - I/I_c)^{-1/4}$ along the current and $L_y \sim \xi(1 - I/I_c)^{-1/2}$ perpendicular to the current, where ξ is the Ginzburg-Landau coherence length. The activation energy for thermal phase slips scales as $\Delta F^{(2D)} \propto (1 - I/I_c)^{3/4}$. For sufficiently wide strips of width $w \gg L_y$, it is energetically favorable to form a half-instanton near the boundary, with the activation energy being 1/2 of $\Delta F^{(2D)}$.

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Integrated cryogenic superconductor qubit control system

I. I. Soloviev, M.M. Khrenov, G.S. Khismatullin, G.I. Gubochkin, R.D. Yusupov, S.V. Bakurskiy, V.A. Vozhakov, M.V. Bastrakova, M.A. Sergeev, M.M. Khapaev, S.V. Egorov, A.S. Ionin, I.A. Nazhestkin, S.A. Lisitsyn, D.S. Yakovlev, V.V. Ryazanov, N.V. Klenov, M.Yu. Kupriyanov

Corresponding Author: I. I. Soloviev

Email:

В докладе представлен обзор современного состояния создания интегральных криогенных систем управления квантовыми процессорами на сверхпроводниковой платформе. Представлена возможность разработки систем управления с использованием подхода мультиплексирования сигналов в микроволновом диапазоне. Показаны варианты таких систем, а также результаты работы по созданию их цифровых и аналоговых компонент, разрабатываемых на базе существующих технологических возможностей в России.

Ballistic transport in nanocrystals of topological insulators

V. S. Stolyarov

Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia

Corresponding Author: V. S. Stolayrov

Email: stolyarov.vs@phystech.edu

Low-dimensional semiconductor-based superconducting proximity devices can achieve ballistic transport regimes. Topological insulators are particularly attractive for such applications due to their unique electronic properties and potential for hosting proximity-induced topological superconductivity. Here we report the successful fabrication and characterization of Josephson devices incorporating few-unit-cell-thick $Bi_2Te_{2.3}Se_{0.7}$ nanocrystals. Our measurements reveal that single-nanocrystal junctions exhibit conventional planar Josephson junction behavior, while dual-nanocrystal configurations function as nanoscale superconducting quantum interference devices (nano-SQUIDs). The distinct temperature and magnetic field dependence of the Josephson current, combined with observed excess current effects, provide strong evidence for ballistic transport through topological surface channels. These results demonstrate that our devices serve as an effective platform for investigating two-dimensional topological superconductivity and related quantum phenomena.

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Self-generated time crystal in superconductor ferromagnet heterostructure

J. Tekić [1], M. Nashaat [2,3], and Yu. M. Shukrinov[3,4]

[1] "Vinča" Institute of Nuclear Sciences, Laboratory for Theoretical and Condensed Matter Physics - 020, University of Belgrade, PO Box 522, 11001 Belgrade, Serbia
[2]Department of Physics, Faculty of Science, Cairo University, 12613, Giza, Egypt
[3]BLTP, JINR, Dubna, Moscow region, 141980, Russia
4Dubna State University, Dubna, Russia

Corresponding Author: Jasmina Tekić

Email: jasminat@vin.bg.ac.rs

Time crystals represent a non-equilibrium state of matter with broken time-translation symmetry that repeats itself at regular time intervals. Though initially envisioned as a self-generated and self-sustained periodic motion, their realization has usually required the utilization of external periodic inputs. In this work, we demonstrate the appearance of a self-generated space-time crystalline order in hybrid Josephson junctions with the ferromagnet interface without any external influence. The presence of the exchange and the Dzyaloshinskii–Moriya interactions in a ferromagnetic layer with broken structural inversion symmetry internally modulates the critical current due to the coupling between the magnetic moment and the Josephson phase. This breaks the time translation symmetry, leading to the appearance of the space-time crystalline order in the spatiotemporal dependence of superconducting current, which evolves with the double of the modulation frequency. Due to its unique origin and properties, this inherent time-crystalline order stands out from the commonly known classification of time crystals into discrete and continuous ones. A self-generated time crystal is demonstrated in two types of hybrid Josephson junctions: the superconductor-ferromagnet-superconductor on a topological insulator and the superconductor-three layer ferromagnet-superconductor. We also show that a recently developed magnetometry device that visualizes a supercurrent flow in the Josephson junction at the nanoscale can be used for experimental detection of time crystals in hybrid Josephson junctions.

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Development and measurement of a cryogenic microwave generator based on Josephson junction planar technology

R. Tyumenev [1], D.S. Kalashnikov[1], A. G. Shishkin [1,2], V. S. Stolyarov [1,2,3]

[1]Advanced Mesoscience and Nanotechnology Centre, Moscow Institute of Physics and Technology, Dolgoprudny 141700, Russia
[2]All-Russian Research Institute of Automatics n.a. N.L. Dukhov (VNIIA), 127030, Moscow, Russia
[3]LPEM, UMR-8213, ESPCI Paris, PSL, CNRS, Sorbonne University, 75005 Paris, France

Corresponding Author: R. Tyumenev

Email: tiumenev.r@phystech.edu

Physical systems used for quantum computing operating in the microwave range require advanced control electronics, and the use of integrated components operating at the temperature of quantum devices is potentially beneficial. In [1], a generator operating at a temperature of 20 mK at a frequency corresponding to the control of qubits was demonstrated. However, the manufacturing technology of this device is quite time consuming. In this paper, we consider a generator consisting of a Josephson junction, a microwave resonator, a shunt capacitance and a resistance. The aim of the work is to determine the range of generator parameters in which stable generation is possible by numerical solution of the system dynamics equations, the manufacture of individual generator elements, as well as the search for its optimal parameters using modeling taking into account the obtained generator elements.

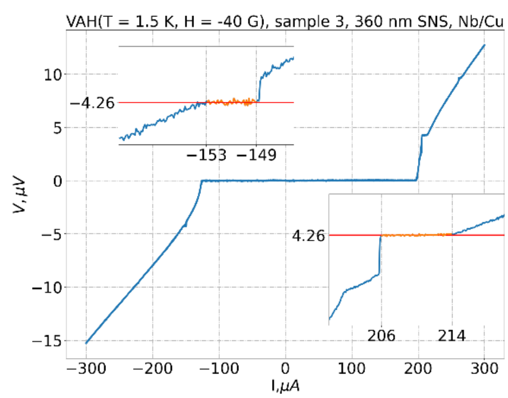

Fig. 1. The volt ampere characteristic of the real sample, the Shapiro stage, indicates the generation of a microwave signal

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Superconducting Magnonics: Electromagnetic Proximity Effect and Beyond

Tao Yu [1], Xi-Han Zhou [1], Gerrit E. W. Bauer[2,3], I. V. Bobkova[4,5]

[1] School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China
[2]WPI-AIMR and Institute for Materials Research and CSRN, Tohoku University, Sendai 980-8577, Japan
[3]Kavli Institute for Theoretical Sciences, University of the Chinese Academy of Sciences, Beijing 100190, China
[4]Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Moscow region, Russia
[5]National Research University Higher School of Economics, 101000 Moscow, Russia

Corresponding Author: Tao Yu

Email: taoyuphy@hust.edu.cn

The interaction between superconductors (SCs) and ferromagnets (FMs) in bilayers by the contact exchange interaction has been the central topic in condensed matter physics for decades. This presentation focuses on new developments along a different route that focuses on the non-contact dipolar interaction between the excited states of the ferromagnet and the superconducting order. The dynamic stray magnetic field displays a universal photonic spin-orbit coupling and corresponding polarization-momentum locking that leads to a chiral screening by proximate superconductors. The associated Meissner effect enables superconductor gates on magnetic films to act as non-dissipative repulsive potential barriers that confine spin transport, generate new magnonic phases, and add functionalities to SC|FM|SC Josephson junctions.

We summarize the theoretical and experimental developments of the past five years, showing that superconducting or metallic strips on top of ferromagnets can chirally gate magnons. We address electromagnetic proximity effects such as enhanced magnon transport, novel magnonic crystals, controllable switching of superconducting states, superconducting magnon transistors, ultrastrong magnon-photon coupling for quantum information processing, and dipolar spin pumping into triplet superconductors. We extend the results for superconductors to that of highly conducting normal metals by a conversion relation that consists of replacing London’s penetration depth by the microwave skin depth. This allows us to translate results from magnon-Cooper pair interactions to formulate the effects of chiral damping. The solution of the associated non-Hermitian chiral Hamiltonian leads to the prediction of a switchable magnon Peltier effect, a chiral magnon non-Hermitian skin effect, nodal

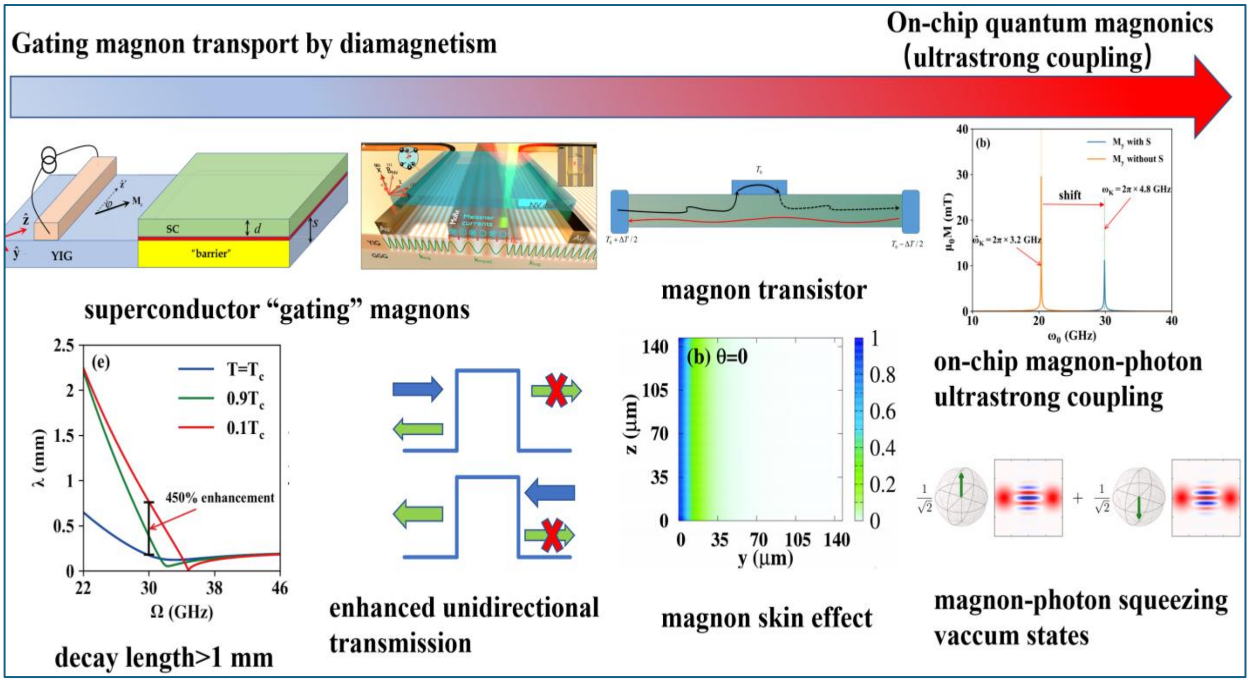

Fig. 1. Typical effects in superconducting magnonics

magnon-photon polaritons, and anomalous scattering of spin waves at semi-transparent potential barriers.

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Rabi-Josephson dynamical transition in trapped superfluids

V.I. Yukalov[1,2] and E.P. Yukalova[3]

[1]Bogolubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia

[2]Instituto de Fisica de Sao Carlos, Universidade de Sao Paulo, CP 369, Sao Carlos 13560-970, Sao Paulo, Brazil

[3]Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna 141980, Russia

Corresponding Author: V. I. Yukalov

Email: yukalov@theor.jinr.ru, yukalova@theor.jinr.ru

The system of trapped Bose atoms at zero temperature is considered. The trap shape or atomic interactions can be modulated by means of external magnetic fields. This allows for the generation of non-ground-state condensates. Several nonlinear modes of Bose-Einstein condensate, supported by modulating magnetic fields, demonstrate rich dynamics, including Rabi oscillations, Josephson dynamics, and chaotic motion. The emphasis is on the Rabi-Josephson dynamic transition, which is shown to be similar to a phase transition in equilibrium systems.

Polarized neutron scattering for 2D periodic and Fibonacci heterostructures

Zhaketov V. [1,2]

[1] Joint Institute for Nuclear Research, Dubna, Russia
[2]Moscow Institute of Physics and Technology, Dolgoprudny, Russia

Corresponding Author: V. Zhaketov

Email: zhaketov@nf.jinr.ru

Low-dimensional magnetic and superconducting heterostructures show complex phenomena due to competing order parameters. While periodic superconductor/ferromagnet (S/F) systems are well studied, quasiperiodic structures remain less explored. Building on previous polarized neutron reflectometry (PNR) work [1-3], this study examines more complex layered architectures and novel properties in quasiperiodic systems. PNR measurements were conducted at the REMUR reflectometer (IBR-2, Dubna), providing depth-resolved nuclear and magnetic profiles. Samples were prepared via various thin film deposition methods. Data analysis involved modeling reflectivity to extract scattering length density profiles. In periodic S/F heterostructures (e.g., Al_2O_3//Nb(40 nm)/$[Dy(6\ nm)/Ho(6\ nm)]_{34}$/Nb(10 nm)), magnetic ordering changes were detected below the superconducting transition temperature [4], attributed to proximity-induced superconducting correlations. Preliminary results on quasiperiodic structures demonstrate the feasibility of their creation and PNR characterization. The observed modification of helimagnetic ordering confirms the strong interplay between superconductivity and magnetism at the S/F interface, with a transition from fan-shaped to helimagnetic states driven by superconducting proximity effects. Extending this to quasiperiodic systems may reveal novel physics such as fractal superconductivity and long-range magnetic order without translational symmetry. Current limitations include the need to optimize sample fabrication and data analysis to better resolve complex scattering profiles. Overall, this work highlights PNR's power in studying intricate S/F interactions and opens new directions for investigating magnetic and superconducting phenomena in quasiperiodic heterostructures. Further studies will focus on detailed analysis of magnetic ordering and superconducting correlations in these low-symmetry systems.

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