Master's Thesis Topics for the academic year 2023-2024

Interface between Quantum and Classical computers

A software tool will be developed to interface quantum with classical computers. This interface will manage the transfer of data and results between the two systems. Additionally, it will determine the suitable standard quantum algorithm for data processing. When interfacing High-Performance Computing systems with a quantum computer cloud, it will also choose the quantum computer with the optimal number of qubits and the shortest job queue.

Master thesis examination committee.

Ioannis Karafyllidis (Supervisor)
Georgios Sirakoulis
Panagiotis Dimitrakis

Evaluation, Implementation and Quantum Analysis of Lattice-Based Cryptographic Algorithms.

Literature overview of quantum cryptographic algorithms. Lattice-based cryptographic quantum algorithms will be reviewed and evaluated using quantum computational methods. Quantum Resistance Strategies and Challenges will be studied. The aim of the thesis would be to further study the Lattice-based cryptographic system both in terms of efficiency and Quantum Resistance but also as a new domain of Quantum advancement.

Master thesis examination committee.

Ioannis Karafyllidis (Supervisor)
Kyriakos Zoiros
Panagiotis Dimitrakis

Fire spreading prediction algorithm using hybrid quantum neural networks for vegetation classification.

A quantum neural network that classifies vegetation areas based on satellite data will be developed. A quantum algorithm will be developed to use the classification data aiming in predicting rural fire spreading.

Master thesis examination committee.

Ioannis Karafyllidis (Supervisor)
Ioannis Boutalis
Georgios Sirakoulis

Quantum algorithm for satellite data processing.

A quantum algorithm for processing satellite data will be developed. This algorithm will focus on crop production and the detection of compositional differences in areas over various time frames. Additionally, a method to predict natural disasters using satellite data will also be developed.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Kyriakos Zoiros
Georgios Dimitrakopoulos

Quantum games on networks.
A model for quantum players on a line will be developed. Each quantum player will play the quantum game with his left and right neighbor. The quantum game model will be extended to graphs, in which each vertex will correspond to a quantum player and each edge to the quantum game circuit.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Kyriakos Zoiros
Panagiotis Dimitrakis

Multiplayer quantum games.
A model for quantum games with more than two players will be developed. The effect of quantum superpositions on quantum player strategies will be studied. Additionally common information shared between players will be modeled as entanglement between players. The total effect of quantum superposition and entanglement on the players payoffs will also be studied.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Kyriakos Zoiros
Panagiotis Dimitrakis

Quantum Bayesian Networks
Bayesian networks, serving as decision support systems, aim to uncover dependencies among variables to determine cause-and-effect relationships. This challenge is recognized as P-hard. In Bayesian networks, quantum circuits employ controlled rotation gates to depict conditional probability tables. These quantum Bayesian circuits have the potential to improve survey analyses by updating the probabilities of latent states in light of observed data, while integrating the principles of entanglement and superposition.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Georgios Sirakoulis
Panagiotis Dimitrakis

Efficient initialization of quantum dot spin states in the Voigt geometry

Electron and hole spin states in semiconductor quantum dots are very important in quantum information technologies. Their manipulation can be efficiently achieved by the application of electromagnetic pulses. A particular system that has attracted significant attention in this research area is based on the spin states of a quantum dot in the Voigt geometry. An interesting basic problem for the quantum dot electron spin states in the Voigt geometry is the initialization, i.e., the preparation of one of the two electron spin states starting from an equal incoherent mixture, which is the natural initial state of the system. In this diploma thesis, the student will explore two different control methods for the initialization of the quantum dot spin states, namely optical pumping and adiabatic preparation and compare the fidelity (efficiency of initialization) of the two methods for different parameters of the system.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Exploring the efficiency of quantum state transfer in a topological chain under dephasing

Quantum state transfer (QST) is a fundamental process in quantum information science, where a quantum state is transferred from one location to another with high fidelity. QST is crucial for various applications in quantum communication, quantum computing, and quantum networks, but it is sensitive to disorder effects as well as to environmental noise. Topological chains have garnered significant interest as a robust platform for QST due to their inherent topological protection. This protection helps maintain the integrity of quantum states even in the presence of disorder or imperfections, which are common challenges in quantum computing and information processing. However, the impact of dephasing noise on the efficiency of QST in topological chains remains unclear. This thesis aims to investigate the efficiency of QST in topological chains under dephasing noise. The student will employ a theoretical framework to simulate the quantum dynamics of a topological chain and perform numerical calculations to study the effects of dephasing noise on the QST efficiency. The case of a specific topological chain will be contrasted to the case of a conventional chain. The student will also explore the potential of quantum control techniques to improve the QST efficiency and reduce the impact of dephasing. The results of this thesis have implications for the design of topological quantum computing architectures and the development of novel control strategies for quantum information processing.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Controlled entanglement dynamics of excitons in colloidal quantum dots

Colloidal quantum dots (CQDs) are a promising platform for quantum information processing due to their ability to generate and manipulate entangled excitons. This thesis aims to investigate the controlled entanglement dynamics of excitons in CQDs using optical control techniques. The student will employ a theoretical framework to simulate the dynamics of the excitons in CQDs and study the potential to control the entanglement dynamics using specific laser pulses. Specific CQDs will be studied where their characteristics have been obtained from ab initio electronic structure calculations. This thesis contributes to the understanding of the controlled entanglement dynamics of excitons in CQDs and provides insights into the development of novel control strategies for quantum information processing. The results have potential applications in quantum computing, quantum communication, and quantum metrology.

Master thesis examination committee

Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Nonlinear optical effects in a coupled semiconductor quantum dot – metal nano-ellipsoid structure

This master's thesis investigates the nonlinear optical effects in a coupled semiconductor quantum dot (QD) - metal nano-ellipsoid (NE) structure, with a focus on the interplay between biexciton effects and plasmonic interactions. The QD is excited by a pump electromagnetic field, leading to the creation of biexcitons, which interact with the NE's plasmonic modes. The nonlinear optical effects are also simultaneously probed by a weak electromagnetic field. The resulting nonlinear optical effects are studied theoretically and numerically, exploring the impact of these interactions on the system's optical response. The results of this study demonstrate the potential of the coupled QD-NE structure for developing novel quantum optoelectronic devices and sensors, with enhanced performance due to the synergistic effects of biexcitons and plasmonics.

<u>Master thesis examination committee</u>
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Exploring single-photon generation in a semiconductor quantum dot structure

The generation of single photons is of major importance in several quantum technology applications. On demand single photon generation from semiconductor quantum dots has been shown with high efficiency in several cases and for different quantum dot structures. The student will first review the relevant literature and then study single photon generation in a specific, previously unexplored, quantum dot structure. The two-time intensity correlation function of the emitted photons will be calculated and the bunching–antibunching transition of the photons in resonance fluorescence from the studied quantum dot structure will be analyzed for different relevant parameters.

<u>Master thesis examination committee</u>
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Tunneling induced transparency in coupled quantum dots: An analysis using exceptional points and its applications in quantum technologies

This master's thesis project aims to investigate the phenomenon of tunneling induced transparency (TIT) in coupled quantum dots, utilizing non-Hermitian quantum mechanics and the emergence of exceptional points. TIT is a fascinating phenomenon where the transparency of a quantum system is enhanced by the coupling of two or more quantum systems through tunneling. The student will study the non-Hermitian Hamiltonian of the system, derive the equations of motion for the density matrix which will use for the calculation of the relevant electric susceptibility, and employ the emergence of exceptional points to analyze the behavior of the system. The student will also explore the properties of the system and discuss their implications for quantum information processing and sensing. The expected outcomes of this project include a deeper understanding of the mechanisms underlying TIT in coupled quantum dots, as well as the development of new methods for controlling and optimizing the transparency of such systems.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Reinforcement learning control for the fast and robust creation of single qubit quantum gates

This master's thesis proposes a novel approach to the control of a qubit using reinforcement learning (RL) techniques, with the goal of fast creation of single qubit gates with very high efficiency and robustness by using different RL methods. In this project, the student will develop a machine learning framework that learns to optimize the control pulses for quantum gate operations, such as the Hadamard gate, by interacting with the qubit and receiving feedback on its performance. The RL agent will apply pulsed excitation to the qubit and measure its response, using the reward function to maximize the fidelity of the quantum gate operation. The expected outcomes of this project are optimized control pulses for high-fidelity quantum gate operations, improved scalability, and increased flexibility. Different RL methods will be applied. The student may also compare the results of the RL methods with standard quantum control methods, like GRAPE and Krotov, where their codes are freely available in Python. This research will contribute to the development of more efficient and scalable methods for creating quantum gates, essential for large-scale quantum computing and quantum information processing.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Fast and efficient creation of two-qubit quantum gates with reinforcement learning methods

This master's thesis proposes a novel approach to the control of a qubit using reinforcement learning (RL) techniques, with the goal of fast creation of two-qubit gates with very high efficiency by using different RL methods. In this project, the student will develop a machine learning framework that learns to optimize the control pulses for two-qubit quantum gate operations, such as the controlled NOT and the controlled-phase, like the controlled Z, gates, by interacting with two qubits in a specific quantum platform, and receiving feedback on its performance. The RL agent will apply pulsed excitation to the qubit and measure its response, using the reward function to maximize the fidelity of the quantum gate operation. The expected outcomes of this project are optimized control pulses for high-fidelity quantum gate operations, improved scalability, and increased flexibility. Different RL methods will be applied. This research will contribute to the development of more efficient and scalable methods for creating quantum gates, essential for large-scale quantum computing and quantum information processing.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Quantum correlations in qubits near graphene nanodisks

This thesis will investigate the quantum correlations that arise between qubits near graphene nanodisks. Graphene has unique electronic properties that make it an attractive material for quantum information processing. The interaction between quantum emitters and graphene nanodisks can lead to interesting quantum phenomena, such as strong coupling at the single photon level, quantum interference in spontaneous emission, and strong coupling between the emitters. These effects can be explored for a large degree of quantum correlations, like entanglement and quantum discord. The project will use theoretical models and numerical simulations to study the quantum correlations between qubits when placed in close proximity to graphene nanodisks. Various parameters, such as the distance between the qubits and the nanodisks, the size of the nanodisks, and the strength of the interactions, will be varied to understand their effects on the quantum correlations. Understanding these correlations is crucial for the development of quantum technologies, such as quantum computing and quantum communication. The results of this study will provide insights into the potential applications of graphene in quantum information processing and pave the way for further research in this field.

<u>Master thesis examination committee</u>
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Quantum simulation of dynamics of open quantum systems

Accurate simulation of the time evolution of a quantum system in the presence of an environment is crucial for making reliable predictions in various scientific and technological fields. While a closed quantum system can typically be described by unitary time evolution, simulating open quantum system dynamics presents a challenge due to the non-Hermitian nature that results in nonunitary evolution. Recent advances have been made in this area, paving the way for further exploration. This Master thesis project will involve a thorough review of relevant literature on methods for simulating the dynamics of open quantum systems. The student will select one of these methods, thoroughly explain its steps, and apply it to simulate the dynamics of a basic quantum system. A comparison of the results obtained will be made with existing literature. Furthermore, the methodology may be extended to explore the dynamics of a new problem not yet studied in the literature.
Proficiency in quantum mechanics, quantum computing, and open quantum systems is essential for this project. The student will also need to be skilled in programming languages commonly used for quantum computing simulations, such as Python or Qiskit and should also be competent in analytical calculations. Conducting a comprehensive literature review, implementing the chosen simulation method, and analyzing the results will be part of the student's responsibilities. Access to a quantum computer or quantum simulator will be required for running simulations.
Overall, this Master thesis project offers an opportunity to develop valuable knowledge and skills in quantum computing and open quantum systems, contributing to advancements in quantum simulation research.

<u>Master thesis examination committee</u>
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos

Dionisis Stefanatos

Quantum control of non-Markovian quantum evolution using tensor networks

Accurately simulating the behavior of quantum systems when interacting with their environment is crucial for the advancement of quantum technology. While open quantum systems are well understood under weak environmental influence, modeling general systems beyond this limit remains a challenging task. Currently, almost all existing approaches to addressing this issue involve making assumptions about the system and its environment. This master thesis uses a different approach based on a recently developed general and efficient numerical technique for calculating observables of open quantum systems. The method involves expressing the precise equations of motion governing the evolution of a general open quantum system as a tensor network. This allows for decomposition in terms of matrix products that can be compressed in size for efficient computation. The project will involve understanding the method, reviewing relevant literature and basic equations, installing and using the necessary codes, and then applying the method to an original quantum control problem in a solid-state quantum device in a complex environment.

<u>Master thesis examination committee</u>
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisis Stefanatos

Rapid charging of a quantum battery composed of a pair of spins with Heisenberg coupling using optimal control

In the context of quantum thermodynamics, quantum batteries are a new concept aimed at storing and releasing energy efficiently. In this thesis, we focus on the development of an optimal control strategy for fast charging a quantum battery composed of a pair of spins with Heisenberg coupling. The Heisenberg coupling is a fundamental interaction commonly encountered between two spin-1/2 particles. In this project we will employ optimal control techniques to design and optimize the control fields that minimize the charging time of the aforementioned quantum system. The optimal control problem will be formulated as a maximization problem, where the objective function is the energy transfer from the external energy source to the quantum battery. The outcome of this thesis has potential applications in various fields, including quantum computing, quantum communication, and energy storage. The findings can also contribute to the development of new technologies that rely on efficient energy transfer and storage.

<u>Master thesis examination committee</u>
Dionisis Stefanatos (supervisor)
Emmanuel Paspalakis
Ioannis Thanopulos

Maximizing entanglement in a pair of spins with Ising coupling using optimal control

Entanglement is a fundamental concept in quantum mechanics, which is essential for various quantum information processing applications. In the context of spin systems, entanglement is a key resource for quantum computing, quantum sensing and quantum communication. One of the most popular spin systems is the Ising model, which consists of two spins interacting via an Ising coupling. In this project we aim to use optimal control for maximizing entanglement is such a pair of spins. Specifically, the goal is to find the optimal time-dependent magnetic fields which drive the system to the state with maximum concurrence and thus entanglement in the least possible time. The results of this research are expected to contribute to the development of more efficient quantum algorithms and protocols for modern quantum technology applications, like computing, sensing and communications.

Master thesis examination committee
Dionisis Stefanatos (supervisor)
Emmanuel Paspalakis
Ioannis Thanopulos

Improving unconventional photon blockade with optimal control

Photon blockade is a phenomenon in which the emission of photons from a quantum system is suppressed due to the presence of an already emitted photon. This phenomenon has been experimentally observed in various systems, including superconducting circuits, optical fibers, and atomic systems. In recent years, unconventional photon blockade has been explored, where the suppression of photon emission is induced by exploiting the quantum interference between different transition pathways. The goal of this thesis is to improve unconventional photon blockade in a bosonic Josephson junction using optimal control methods for the design of the coupling between the two nonlinear bosonic modes. Specifically, we aim to find lower values of the second-order correlation function obtained at earlier times than with constant coupling, with larger one-photon populations and for longer time windows. The present research is expected to find application in the efficient design of single-photon sources, which are an essential element for modern quantum communications.

Master thesis examination committee
Dionisis Stefanatos (supervisor)
Emmanuel Paspalakis
Ioannis Thanopulos

Polychromatic adiabatic passage scheme for quantum information encoding

Polychromatic adiabatic passage schemes combine the high-selectivity between different target states achieved by coherent control methods with the effectively complete transfer of population under few-level adiabatic passage schemes. Such quantum control schemes have been in the center of the research on quantum control since its inception due to their evident potential for manipulating quantum systems and developing quantum technological applications. In this diploma thesis, the use of polychromatic adiabatic passage schemes for quantum encoding and decoding purposes is investigated on non-degenerate quantum systems. The dynamics of such processes are studied in the relevant quantum state subspace of dark states. The necessary parameters of the encoding laser fields required for achieving a target quantum information state by given a known initial state are determined. Also, the inverse process of developing a decoder for a given quantum information state is addressed.

Master thesis examination committee
Ioannis Thanopulos (supervisor)
Emmanuel Paspalakis
Dionisios Stefanatos

Controlling the quantum light group velocity by cavity induced transparency: single-photon emission and interference effects

The propagation of a quantized probe field in a dense medium composed of three-level Λ-type quantum systems under conditions of electromagnetically induced transparency conditions is a topic which has attracted the interest of recent research activity due to its fundamental scientific importance as well as numerous potential applications in nanophotonics and quantum technologies. In this diploma thesis, the group velocity of a probe pulse propagating under such conditions in a cavity is investigated in the weak and strong light-matter coupling regime. The possibility of photon-number selectivity on the group delay and the creation of single-photons on demand is studied. Also, the possibility of interference effects between different photon components in the probe pulse is addressed.

Master thesis examination committee
Ioannis Thanopulos (supervisor)
Emmanuel Paspalakis
Dionisis Stefanatos

Degree of non-Markovianity and quantum speed limit under strong coupling at the nanoscale

The proposed master thesis project aims to study the degree of non-Markovianity and the quantum speed limit in the spontaneous emission evolution of a quantum emitter coupled to a specific photonic nanostructure. The study will investigate how various vacuum decay rates and distances affect these key quantum properties in the system. The research will employ well-established measures of non-Markovianity to quantify the extent to which memory effects are present in the evolution of the quantum emitter. Additionally, the possibility for substantial dynamical quantum speedup will be analyzed, considering how the coupling to the photonic nanostructure can influence the emission dynamics of the quantum emitter. By exploring these aspects, the project aims to deepen our understanding of the quantum behavior of coupled systems and contribute to the development of quantum technologies. The study will utilize theoretical tools and computational simulations to investigate the dynamics of the system under different conditions, with the ultimate goal of shedding light on the interplay between non-Markovianity and quantum speed limits in the context of spontaneous emission processes, which is crucial for various application in quantum technologies.

Master thesis examination committee
Ioannis Thanopulos (supervisor)
Emmanuel Paspalakis
Dionisis Stefanatos

All-Optical Quantum Logic Gates

This subject concerns the design, development, implementation and practical use of quantum logic gates executed exclusively by means of light for the realization of optical quantum communications circuits, systems and networks of enhanced functionality and performance.

Master thesis examination committee
Kyriakos Zoiros (supervisor)
Ioannis Karafyllidis

Christos Schoinas

Free Space Optics for Optical Quantum Communications

This subject concerns the current status, future trends, and practical challenges of free space optics to enable leveraging the potential of this technological platform in optical quantum communications and applications such as quantum cryptography.

Master thesis examination committee
Kyriakos Zoiros (supervisor)
Ioannis Karafyllidis
Christos Schoinas

Data Clustering with Quantum Computing

First, a literature review of classical clustering techniques will be done. Next, a review will be made of the above techniques that have been implemented with quantum computing. Selected algorithms will be implemented to show the results in relation to the benefit in computational cost and accuracy of the solutions

Master thesis examination committee
Ioannis Boutalis (supervisor)
Georgios Syrakoulis
Ioannis Karafyllidis

Quantum K Nearest Neighbors Algorithms

First, a literature review of classical K-NN algorithms with applications in data classification and regression. Next, a review will be made of the above techniques that have been implemented with quantum computing. Selected algorithms will be implemented to show the results in relation to the benefit in computational cost and accuracy of the solutions

Master thesis examination committee
Ioannis Boutalis (supervisor)
Georgios Syrakoulis
Ioannis Karafyllidis

Quantum algorithms in Artificial Neural Networks

Quantum algorithms will be implemented and tested to run various aspects of algorithms of ANN training and operation on a quantum computer. Classical ANN algorithms will be studied first, and a set of classical algorithms will be selected that could be quantized and benefited from the quantum implementation. Aspects of computational complexity, accuracy and generalization performance will be investigated in order to derive useful conclusions on the appropriateness of the quantized versions of the algorithms.

Master thesis examination committee
Ioannis Boutalis (supervisor)
Georgios Syrakoulis
Ioannis Karafyllidis

Genetic Algorithms with Quantum Computing

Quantum algorithms that can be used in various aspects of genetic algorithms implementation will be selected and implemented. First, genetic algorithms and its variants will be reviewed from the classical literature. Then those aspects of genetic algorithms that could be benefited from implementing them with quantum computing will be selected. Moreover, the advantages in terms of computational complexity will be studied, and the effect that quantum computing will have on the correctness of the results in relation to classical algorithms will be presented.

Master thesis examination committee
Ioannis Boutalis (supervisor)
Georgios Syrakoulis
Ioannis Karafyllidis

Meta analysis of transcriptomic data of a disease

Transcriptomic data (e.g. single cell RNA-seq, etc) could provide information about the effect of a disease into the transcriptional profile of the genes of the organism. The aim of the thesis would be to perform a meta-analysis of publicly available transcriptomic data, in order to unveil the effect of the disease into the expression profile of the genes, by combing and integrating data from various studies.

Master thesis examination committee
Petros Kolovos (supervisor)
Raphael Sandaltzopoulos
Aristotelis Papageorgiou

Quantum Computing and Quantum Machine Learning in the Life Sciences

The potential of quantum computing and quantum machine learning in life sciences has captured the attention of both the research community and the pharmaceutical industry, historically reliant on classical computing for research. As these fields evolve, they herald a new era of problem-solving capabilities in life sciences.

This MSc thesis will explore specific use cases of quantum computing and quantum machine learning within the life sciences sector. It will discuss their current applications, potential benefits, and the trajectory of these technologies in transforming life sciences research.

Master thesis examination committee
Pavlos Efraimidis (Supervisor)
Ioannis Boutalis

Aristotelis Papageorgiou

Post-quantum cryptography: Concepts and Tools

The security of many contemporary cryptographic algorithms is predicated on the assumption that specific algorithmic problems, such as integer factorization and the discrete logarithm problem, cannot be efficiently solved—that is, not in polynomial time. However, these computational challenges are expected to be surmountable on quantum computers using Shor's algorithm. As such, the advancement of quantum computing technology represents a formidable threat to the integrity of existing cryptographic systems.

Post-quantum cryptography encompasses the development of cryptographic algorithms designed to be secure against attacks by quantum computers. This field involves identifying and devising new algorithms rooted in mathematical problems considered intractable for both quantum and classical computational approaches. This MSc thesis will delve into the current landscape of post-quantum cryptography, analyzing its development and assessing practical tools and libraries implemented in the field.

<u>Master thesis examination committee</u>
Pavlos Efraimidis (Supervisor)
Ioannis Boutalis
Ioannis Karafyllidis

Rabi oscillations and measurement of the rotating frame spin relaxation time $T_{1\rho}$ of atomic hydrogen
The longitudinal T_1 and transverse T_2 spin relaxation times cannot provide a complete description of the relaxation of dressed spins which are subject to resonant microwave (mw) irradiation. In the rotating frame (on-resonance), the quantization axis x of dressed spins is distinguished from y, therefore, relaxation along the two directions is expected to be different ($T_2/2<T_{1\rho}<T_1$). This thesis will study the $T_{1\rho}$ times of H@POSS (POSS: polyhedral oligomeric silsesquioxane) and will determine the spectral density $J(\omega_1)$ at the nutation frequency ω_1. The student will apply different pulse schemes comprising high turning angle (HTA) pulses and FID (free induction decay) or echo detection. The results will allow evaluating for the first time the spin relaxation properties of H@POSS under the application of quantum gates which are based on long resonant mw pulses.
<u>Master thesis examination committee</u>
George Mitrikas (supervisor)
Yiannis Sanakis
Michael Pissas

Magnetic characterization of a polynuclear transition cluster.

Polynuclear transition metal clusters (PTMC) have been proposed as possible candidates for the realization of qubits. In the present master thesis, the student will apply experimental methods in order to characterize the magnetic properties of a PTMC, based on transition metal and lanthanide ions. The characterization involves application of variable temperature, variable magnetic field static and dynamic magnetic susceptibility measurements, variable temperature Mössbauer Spectroscopy and variable temperature Continuous wave Electron Paramagnetic Resonance EPR spectroscopy. These studies will provide information about the nature of the spin value of the ground state, the exchange coupling scheme between the ions, the contribution of non-isotropic exchange terms, the composition of the eigenstates, and the temperature dependence of the spin relaxation time.

Master thesis examination committee

Yiannis Sanakis (supervisor)
George Mitrikas
Michael Pissas

Photosystem II Inspired Spin-Based Quantum Computing Devices

Photosystem II (PSII) is a naturally occurring system that can be isolated from higher plants and catalyzes the photoinduced water oxidation. The PSII apparatus comprises paramagnetic species positioned in a well-organized topology dictated by the proteinic environment. The light induced electron transfer that occurs within PSII can be controlled and certain paramagnetic species can be trapped leading to pairs comprising these species. These magnetically exchanged pairs could constitute the prototype to realize a spin-based quantum computing device (SBQCD). In order to do this, it is necessary to characterize in fine detail the magnetic interactions within these pairs by applying continuous wave EPR at X (9.5 GHz) and Q (34 GHz) and pulsed EPR at X-band at liquid helium temperatures.

Master thesis examination committee

Yiannis Sanakis (supervisor)
George Mitrikas
Michael Pissas

Superconducting qubits based on transmon qubit

The aim of the thesis is the graduate student to write a critical review/study of recent and current developments on superconducting qubits based on transmon qubit.

Master thesis examination committee.

Michael Pissas (Supervisor)
Panagiotis Dimitrakis
Yiannis Sanakis

Use of the qiskit platform to design superconducting qubit

The graduate student will describe the design tools contained in the https://qiskit.org/documentation/metal/ platform. She/He will use these tools to design superconducting qubit. Qiskit Metal is an open-source framework (and library) for designing superconducting quantum chips and devices (https://qiskit.org/documentation/metal/).

Master thesis examination committee.

Michael Pissas (Supervisor)
Panagiotis Dimitrakis,
George Mitrikas

Hybrid electron-nuclear spin two-qubit gates with atomic hydrogen trapped in POSS cages

Hybrid spin systems where an electron spin is hyperfine-coupled to one or more nuclear spins have been the subject of numerous studies despite their intrinsic relaxation incompatibility (typically μs for the electron spin and ms for the nuclear spin) which, due to relaxation losses, poses an *a priori* limitation on the implementation of two-qubit quantum gates (QGs). Atomic hydrogen trapped in polyhedral oligomeric silsesquioxane cages (H@POSS) is a unique system possessing an unpaired electron spin located at the trapped H atom and a ^{29}Si nuclear spin at the core of the POSS cage interacting with a hyperfine coupling being at the so-called exact cancelation condition. The student will theoretically estimate the experimental conditions under which such a system could be the building block for two-qubit QGs and will evaluate their fidelities based on existing experimental spin relaxation data.

<u>Master thesis examination committee</u>
George Mitrikas (supervisor)
Yiannis Sanakis
Michael Pissas

Clock spin-transitions of atomic hydrogen

Electron spins in molecular spin systems may serve as promising qubits, however, protection from environmental noise that causes decoherence is of critical importance and represents one of the main challenges towards practical applications. As in such systems the main source of decoherence is the modulation of the electron-nuclear interactions, typical strategies to mitigate decoherence include the reduction or complete elimination of magnetic nuclei from the materials. An alternative approach involves exploiting the so-called clock transitions at which the electron paramagnetic resonance (EPR) frequency is insensitive to the local magnetic induction and, therefore, does not couple to the fluctuating magnetic environment. For atomic hydrogen spin clock transitions occur when the static magnetic B_0 is oriented parallel to the microwave B_1 field (parallel mode). The student will study this system in terms of transition probabilities for both ^1H (I=1/2) and ^2H (I=1) isotopes, investigate the properties of the occurring clock transitions, and simulate the expected enhancement of their coherence time T_2.

<u>Master thesis examination committee</u>
George Mitrikas (supervisor)
Yiannis Sanakis
Michael Pissas