PHYS4999 Physics Project (2026-27)

Project HFC4901: Readings in Quantum Computation
Supervisor: Prof. H.F. Chau

This is a reading project focusing on the physics, mathematics, computational science and information science aspects of quantum computation. One should begin by reviewing the Shor's and Gover's algorithms. Then, one can study various topics such as the classification of entanglement, the structure of quantum error correcting codes, quantum noisy coding theorem and the proposed ways to make a quantum computer.

Only those who have come to talk the supervisor will be considered.

Prerequisites: At least 2As and 1B in the following subjects --- Analysis I, Algebra I, Quantum Mechanics, Statistical Mechanics & Thermodynamics, Electromagnetism, Differential Equations, Data Structure And Program Design.

Corequisites: Advanced Statistical Mechanics / Functional Analysis, Advanced Quantum Mechanics

Project HFC4902: Quantum Speed Limits
Supervisor: Prof. H.F. Chau

According to the Schrödinger equation, it takes non-zero time to evolve from one quantum state to another distinct quantum state. In fact, there are fundamental limits, collectively known as quantum speed limits, on how fast such evolution can take place. In this project, you are going to review some of these limits and hopefully find new ones. Students taking this project should have good command in quantum mechanics plus knowledge in either mathematical analysis or computational physics.

Only those who have come to talk the supervisor will be considered.

Prerequisites: At least A and 1B Quantum Physics plus either Introductory Computational Physics, Theoretical Physics or Analysis I

Corequisites: Advanced Quantum Mechanics plus either Computational Physics or Data Analysis And Modeling In Physics

Project XDC4901: Thin film field effect transistors
Supervisor: Prof. X.D. Cui

The project aims to give undergraduate students a hand-on research experience on thin film field effect transistors. One will learn vacuum technique, thin film process, device fabrication and electric characterization during the project. The applications of the thin film devices will be explored in various fields. Intensive hand work training is involved through the project.

Prerequisites: basic knowledge in solid state physics

Project LXD4901: Simulating Black Hole Accretion Disks and Jets
Supervisor: Prof. L.X. Dai

Black hole accretion is one of the most efficient mechanisms in the universe for converting matter into energy. It powers the luminous emissions that we observe from many astrophysical systems such as active galactic nuclei, gamma ray bursts, tidal disruption events, etc. In order to understand what we can observe from black hole accreting systems, one needs to study the structure of accretion disks and jets around black holes. A complete understanding of these often requires numerical simulation due to the complexity of the problem involving general relativity, radiation, gas and magnetic field.

In this project, the student will learn and practice using advanced general relativistic numerical codes to simulate accretion and jets formed around black holes in different astrophysical systems. Topics include simulating Bondi accretion (spherical accretion) which happens in many black hole systems such as low-luminosity AGNs or some types of X-ray binaries, super-Eddington accretion which happens in tidal disruption events, ultra-luminous X-ray sources, and high-redshift quasars, etc.

Project DKK4901: Charge Transports through Graphene and 2D Materials
Supervisor: Prof. D.K. Ki

2D materials represent a family of van der Waals (vdW) coupled layered materials that can be exfoliated down to one or few atomic layers. This provides a unique opportunity to study how charge transports in the same material system evolve with its thickness at an atomic scale. Here, we will study such evolutions for different types of 2D materials, such as metals (e.g., graphene), semiconductors (e.g., WSe2 and MoS2), or insulators (e.g., hBN). In this project, the student will first learn how to exfoliate 2D materials and fabricate devices, and learn how to measure their charge transport properties. Basic concepts of solid-state physics and nano-electronics will also be introduced. As this project will challenge students to become a real experimentalist in the field of quantum nano-electronics, it is recommended only for the student(s) with strong interests in the field and motivation.

Prerequisites: PHYS3551 Introductory Solid State Physics, PHYS3351 Quantum Mechanics

Project LIM4901: Astrophysical Applications of Gravitational Lensing
Supervisor: Prof. J.J.L. Lim

Over the past 6 years, I have formed an ever-growing international collaboration and assembled a group of talented undergraduate and graduate students who use gravitational lensing by galaxies and galaxy clusters to: (i) search for, and verify geometrically the distances of, infant galaxies in the early Universe; (ii) search for and weigh supermassive black holes in galaxies at early epochs; (iii) map the distribution of matter in galaxies and galaxy clusters; and (iv) test different theories for dark matter (e.g., particle vs. wave-like in their collective behavior) based upon their predictions for the luminosity function of galaxies (especially those in the early Universe), and for the positions and magnification of multiply-lensed images of background galaxies. Studies of the early Universe is the main scientific goal of the James Webb Space Telescope (JWST), for which gravitational lensing will play an integral role by providing a cosmic lens to magnify distant and therefore faint galaxies. Our work uses archival data from the Hubble Space Telescope (HST), and newly acquired proprietary data as members of programs on both the HST and the soon to be launched JWST. The first step in our work usually involves the construction of lens models for (i.e., infer the mass distribution associated with) galaxies or galaxy clusters as constrained by the positions and distances of lensed images of background galaxies that have been robustly identified – and then using the preliminary lens model to confirm uncertain or identify new lensed images of background galaxies, and adding these lensed images to refine our lens model. We generate lens models using either or both parametric and non-parametric algorithms depending on the complexity of the lensing mass, the available constraints from multiply-lensed images of background galaxies, as well as the scientific needs of our work. At the present time, one of the primary focus of our work is to compute the effects of granulations inherent in wave-like dark matter on gravitational lensing, in particular on the subtle effects they have on the positions and magnifications of background lensed images – and to compare these predictions with longstanding and newly found (by us and others) anomalies in multiply-lensed images of background galaxies or of their individual stars.

Project LIM4902: Cluster Merger Impact on Central Thermodynamics and Star Formation
Supervisor: Prof. J.J.L. Lim

The majority of elliptical galaxies are red and dead – they comprise primarily low-mass (presumably old) stars, and are no longer (and presumably have long since ceased) actively forming stars. This situation, however, is not always true of giant elliptical galaxies that lie at the centers of galaxy clusters. Such galaxies are the most massive, largest, and most luminous galaxies in the Universe: how they attained their enormous masses and sizes remain an outstanding problem in astrophysics, and have much to teach us about the cosmic growth and evolution of galaxies. Some of these galaxies harbour enormous quantities of relatively cool gas, and are actively engaged in star formation. My research team is addressing how star formation and active galactic nuclei at cluster centers are related to the thermodynamics of the intracluster medium and the cluster dynamical state.

Project CCL4901: Transparent High-dielectric Constant Oxide Thin Film via Acceptor-donor Co-doping
Supervisor: Prof. F.C.C. Ling

Fabrication of capacitive coupling devices like metal oxide semiconductor field effect transistor MOSFET usually involves the gating material having high dielectric constant and low dielectric loss. HfO_2 and its related compounds are the commonly used high-k (k=dielectric constant) for device applications, having a dielectric constant of ~25. In some recent experiments, we have achieved fabricating a high-k ZnO film via acceptor-donor doping, which has a dielectric constant as high as ~180 and dielectric loss as low as ~0.1. The present project aims to optimize the dielectric performance of the material and to study the physics leading to the high-k.

Project CCL4902: Defects in SiC MOSFET
Supervisor: Prof. F.C.C. Ling

Defects in semiconductors determine the electrical properties of the material and the devices. SiC is a promising wide band gap semiconductor for fabricating high temperature, high power, high frequency and radiation resistive devices. In the industrial fabrication process of SiC metal oxide semiconductor field effect transistor (MOSFET), ion implantation is needed realize to selective area doping. However, ion implantation inevitably introduces intrinsic defects which would worsen the device performance. The present study aims to identify the defect created by ion implantation using a variety of techniques including luminescence spectroscopy, deep level transient spectroscopy and positron annihilation spectroscopy. This project is collaboration with the Alpha Power Solutions Ltd and would involve working at their laboratory.

Project TTL4901: Introductory ultrafast optics 3: measurements of ultrashort laser pulses
Supervisor: Prof. T.T. Luu

In this project, the involved students will learn all the concepts in the **TTL3901** and **TTL3902** plus: measurement techniques for ultrashort laser pulses. The students will learn these topics theoretically first. Afterward, they will be able to perform measurement of pulse durations using our existing apparatus. They will learn how the apparatus is made, and they will have opportunity to assemble the apparatus themselves. They will develop theoretical (numerical) simulation of pulse reconstruction. The results will be compared with existing algorithms. In this project, the students will not only learn experimental skills, but they will also be able to make their own numerical simulation and compare it with existing codes to see what they did well and what can be improved. For students with strong performance, an opportunity to develop enhanced measurement apparatus will be provided.

Prerequisite: Analysis I, Algebra I, Electromagnetism, Differential Equations, Quantum mechanics, Waves and Optics (optional)

Project ZYM4901: Quantum many-body physics with numerical investigations
Supervisor: Prof. Z.Y. Meng

In this project, the students will start with basic algorithmic knowledge of statistical and many-body physics, to understand the fundamental principles behind phase transitions, symmetry breaking and computational condensed matter physics. Then the students will have the chance to further explore the advanced topics such as machine-learning approaches in quantum many-body physics, the non-Fermi-liquid and topological state of matter, depending on the progress.

Only those who have come to talk the supervisor will be considered.

Prerequisites: PHYS3151 Machine learning in physics and PHYS4150 Computational physics are strongly recommended. Statistical Mechanics & Thermodynamics. Condensed matter physics, Advanced Quantum Mechanics are recommended.

Project CYN4901: High Energy Emission from Pulsars
Supervisor: Prof. S.C.Y. Ng

Massive star end their lives as violent supernova explosions. The dense cores left over could form neutron stars. Such a star is more massive than the Sun, but has a radius of only 10 km, i.e. about the size of Hong Kong Island. It is therefore extremely dense. Neutron stars also possess the strongest magnetic fields in the Universe and rotate rapidly. These result in strong radiation beams along the magnetic poles, acting as lighthouses. When the beams sweep across the Earth, an observer would detect pulsating signals, hence a neutron star is also called a pulsar. The remarkable properties of pulsars make them an ideal laboratory for testing physics under the most extreme conditions that can never be produced on Earth. In this project, we will study pulsars based on high energy observations in X-rays or gamma-rays, to understand their emission properties and interaction with the environment.

Project SQS4901: Novel Topological States and Quantum Transport in Condensed Matter Physics
Supervisor: Prof. S.Q. Shen

Topological insulator is insulating in the bulk, but processes metallic states present around its boundary owing to the topological origin of the band structure. The metallic edge or surface states are immune to weak disorders or impurities, and robust against the continuous deformation of the system geometry. We found that the modified Dirac equation can provide a unified description of topological insulator and superconductor from one to three dimensions. In this project we shall explore novel topological phases and quantum transport in condensed matters.

Project YJT4901: Searching for New Physics at the ATLAS Experiment at the Large Hadron Collider
Supervisor: Prof. Y.J. Tu

The goal of high-energy physics is to understand the fundamental particles and their interactions. The startup of the Large Hadron Collider (LHC), the world's largest and highest-energy particle accelerator, in 2009 opened up a new era at the high energy frontier. The discovery of the Higgs boson (popularly known as 'the God particle') at the LHC marked the beginning of a golden age for fundamental physics. The unexplored energy domain of the LHC provides unique opportunities to answer the fundamental questions in particle physics, e.g. what is the origin of particle mass? The group is carrying out new physics searches and participating the ATLAS detector upgrade. The projects will involve simulating and analyzing data from the ATLAS experiment (searching for physics beyond the Standard Model). In particular, the project will involve the application of Machine Learning (ML) techniques and the development of ML algorithms in particle physics. Particle physics has a history of several decades of using ML techniques for data analyses. However, most of the efforts heavily relied on traditional ML techniques such as Boosted Decision Trees, where expert-designed observables or model-dependent information are necessary for efficiently detecting new physics. We are developing the techniques of novelty detection which allows the data to be analysed without a priori knowledge of the new physics.

Knowledge required: C++ and Linux programming preferred

Project ZW4901: Magnetic Molecular Intercalation in 2D Materials
Supervisor: Prof. Z. Wan

This project aims to experimentally investigate the coupling between magnetic molecules and two-dimensional materials through intercalation. Students will fabricate hybrid structures by inserting magnetic molecules into van der Waals gaps of layered materials such as graphene or MoS_2, and then characterize how molecular spin states interact with host lattices. The work will involve exfoliation of 2D substrates, intercalation of magnetic molecules, and subsequent structural and chemical characterization using Raman spectroscopy, AFM, and XPS. Magneto-transport measurements under varying temperature and magnetic field will be performed to probe spin-dependent conduction, while optical spectroscopy will be used to study spin－photon interactions and possible signatures of spin-induced band modifications.

The project provides intensive hands-on training in thin-film preparation, device fabrication, and advanced characterization techniques. Students will integrate concepts from condensed matter physics, materials science, and chemistry to build a cross-scale understanding of how molecular magnetism reshapes 2D electronic states. The ultimate goal is to provide direct experimental evidence for bidirectional coupling between molecular spin functions and host lattices, and to explore whether magnetic intercalation can stabilize unconventional quantum phases such as spin liquids or correlated metallic states, thereby advancing the design of programmable “artificial quantum solids.”

Prerequisites: Solid State Physics, Quantum Mechanics, Statistical Physics

Project CJW4901: Topological Phases of Matter with Strong Correlation
Supervisor: Prof. C.J. Wang

Topological phases of matter have gained lots of attention due to their richness and wide connections to other fields of physics. In particular, in certain systems, there exist so-called non-Abelian anyon excitations that can be used for fault-torrent quantum computation. While topological phases with weak correlation can be well understood through conventional mean field theories, it requires many new concepts and tools to understand strongly correlated topological phases. We work on two general aspects of topological phases: (i) fundamental theories of topological phases, in particular in higher dimensions and (ii) search of anyons in experimental systems such as fractional quantum Hall liquids and quantum spin liquids. More specifically, we will investigate the deep interplay between symmetry and topology --- two key fundamental concepts in modern physics --- in various quantum systems. We also plan to perform numerical studies, e.g., using algorithms based on tensor network states of quantum many-body systems.

Project MHX4901: Surface Studies of Crystalline Thin Films
Supervisor: Prof. M.H. Xie

Atoms on the boundary of a crystal, i.e., the surface, usually show different properties than the bulk, including atomic arrangements and electronic properties. In this project, the students will get some hand-on experience in charactering the surface atomic and electronic structures by using such techniques as electron diffraction, photoemission spectroscopy and scanning probe microscopy. The student will be taught about the basics of vacuum technology and thin film growth by molecular-beam epitaxy (MBE), a modern and versatile thin from growth technique, during the course of this project. He/she will participate in one of the research programs in the lab. This project will be suitable for students who are interested in condensed matter experiments and has reasonable background and training in solid state physics. Because the project involves operations of vacuum-based sophisticated apparatus, the student needs to be conscientious and diligent, who is expected to spend more time for training and carrying out the experiments.

Prerequisites: PHYS4551 Solid state physics

Project YY4901: Free-electron light interaction
Supervisor: Prof. Y. Yang

Light-matter interaction between free electrons and photons is a fundamental quantum electrodynamical process. Their interaction is pivotal for many applications, including free electron lasers, microscopy and spectroscopy, and particle accelerators. This project aims to pursue strong interaction strength between free electrons and photons and to put forward realistic designs for experimental realizations

Project YY4902: Photonic synthetic gauge fields
Supervisor: Prof. Y. Yang

Synthetic gauge fields open a versatile toolbox to manipulate geometric phases in engineered physical systems. These gauge fields can be classified into Abelian (commutative) and non-Abelian (non-commutative), depending on the commutativity of the underlying group. This project plans to explore photonic realizations of synthetic gauge fields and their topological consequences. The student will discuss the interplay between non-Hermiticity, nonlinearity, and synthetic gauge fields on photonic platforms.

Project WY4901: Valley Physics in Monolayer Materials
Supervisor: Prof. W. Yao

A trend in future electronics is to utilize internal degrees of freedom of electron, in addition to its charge, for information processing. A paradigmatic example is spintronics based on spin of electrons. Degenerate valleys of energy bands well separated in momentum space constitute another discrete degrees of freedom for low energy carriers with long relaxation time. This has led to the emergence of valleytronics, a conceptual electronics based on the valley index. In a number of monolayer hexagonal crystals including graphene and several transition metal dichalcogenides, the conduction and valance bands have two inequivalent valleys at the corners of the 1st Brillouin zone. The low energy electrons and holes are thus described by massless or massive Dirac electrons with valley degeneracy. In this project, students are expected to learn about valley dependent physics in these emerging novel materials, and may also study feasible problems related to valley and spin control for information processing.

Prerequisites: PHYS3351 Quantum mechanics, and PHYS3551 Introductory solid state Physics (or equivalent courses).

Corequisites: PHYS4351 Advanced quantum mechanics (or equivalent course).

Project SZZ4901: Physics of Very Degenerate Atomic Gases
Supervisor: Prof. S.Z. Zhang

Atomic gases at extremely low temperatures exhibit a range of fascinating phenomena, in which particle statistics and interaction play an important role. As an example, superfluidity has been seen in both Bose and Fermi variants, with the direct observation of vortex arrays and other interference phenomena associated with the phase coherence of the macroscopic quantum states. Recent experimental advances have made it possible to engineer synthetic (abelian or non-abelian) gauge fields which fundamentally changes the nature of the many-body states. These new developments bring out the prominent role played by Berry phases and make atomic gases an idea playground for understanding the topological aspects of interacting many-body systems. In this project, students are expected to learn the fundamentals of this rapidly developing field and possibly explore a few problems of current interest.

Prerequisites: PHYS3351 and PHYS3550

Project S_Z4901: Topological photonics
Supervisor: Prof. S. Zhang

Topologically ordered phases of matter, such as topological insulators and topological semimetals, represent a new class of materials with the unique ability to support protected edge or surface states. Recently it has been shown that the concept of topological order can also be transferred to photonic systems, providing a flexible one-way wave-guiding platform. In this project the students will explore the design of metamaterials and/or photonic crystals with topological orders and study the interesting topologically protected surface/edge states supported by such photonic systems.

Prerequisite: Electromagnetism, Solid-State Physics, Quantum Mechanics

Project S_Z4902: Achieving strong optical activities with chiral metamaterials
Supervisor: Prof. S. Zhang

Natural materials such as sugar water and some organic materials show optical activity, i.e. light of the two circular polarizations has different refractive indices, speed or absorption. The latter is called circular dichroism. However, the optical activity is so weak in natural materials that it is only observable after light passes through a very long distance inside the chiral medium. In this project, the students will try to understand the physics of optical activity, how it is related to the coupling between electric and magnetic responses, and how to design metamaterial to enhance this effect. The students will design and fabricate metamaterials showing much strong optical activities than that of natural materials.

Prerequisite: Electromagnetism, Optics

Project S_Z4903: Microwave plasmonics
Supervisor: Prof. S. Zhang

Plasmonics refers to the interaction between electromagnetic waves and the collective oscillations of electrons in metals. This interaction allows for the confinement of light to the surface of metallic materials. Plasmonics has been extensively utilized in various applications at optical frequencies, such as nanophotonic circuits, superimaging, and molecular sensing. However, at microwave frequencies, electromagnetic waves struggle to penetrate metals. Therefore, specific structures are needed to facilitate the coupling between electromagnetic waves and metals. These structures are commonly known as designer plasmons or spoof plasmons. The aim of this project is for students to explore the design of metallic structures that can strongly confine microwave radiation and manipulate its propagation on a chip or in free space.

Prerequisite: Electromagnetism, optics

Project ZDZ4901: Feedback control of lasers for experiments of cold atoms and ions
Supervisor: Prof. Z.D. Zhang

Precise control of laser beam properties is essential for the production, manipulation and detection of cold atoms and trapped ions, which are fundamental quantum systems for the study of quantum physics, quantum information processing and ultracold chemistry. In this project, students will build feedback circuits with proportional-integral-derivative (PID) controls to stabilize the intensity or frequency of laser beams. Acousto- or electro-optic modulation will be applied for laser beam control. Students will acquire hands-on experience and apply knowledges of electronics, lasers and atomic physics in modern cold atom experiments.

Prerequisites: Electronics, Lasers and Atomic Physics

Project YXZ4902: Stability of topological modes under crystalline chiral symmetry
Supervisor: Prof. Y.X. Zhao

In contrast to ordinary symmetries, chiral symmetry anti-commutes with the Hamiltonian or Dirac operator under consideration. Chiral symmetry plays a seminal role in topology because it can stabilize zero modes. In crystals, chiral symmetry can be realized as sublattice symmetry. What is special is that the sublattice symmetry may have nontrivial algebraic relations with other crystal symmetries. Hence, traditional understandings of the stability of zero modes protected by chiral symmetry may be modified. In this project, students will understand why chiral symmetry can stabilize zero modes and explore the novel phenomena that sublattice symmetry can bring.

Prerequisite: Linear algebra, Quantum Mechanics

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