The Chinese University of Hong Kong
Division of Physics

Experimental Projects Offered in 2020-21

No.	Project title	Degree	Offered by
E1	Experimental high energy physics at the Large Hadron Collider	PhD	Prof. Luis R. Flores Castillo
E2	Electronic and thermal properties of correlated electron systems under extreme conditions	PhD or MPhil	Prof. Swee Kuan Goh
E3	Magnetic fields in star formation	MPhil or PhD	Prof. Hua-Bai Li
E4	Magnetic fields in dense molecular phases of spiral galaxies	PhD	
E5	Probing stellar birth from the Atacama Desert	MPhil or PhD	
E6	Application of diamond quantum sensing in condense matter physics, materials science, and biomedicine	PhD	Prof. Quan Li
E7	Developing in/ex situ tools for mechanistic study of battery process		
E8	Diamond quantum sensing	PhD	Prof. Ren-Bao Liu
E9	In-situ synchrotron characterization of photovoltaic thin films	PhD	Prof. Xinhui Lu
E10	Topics in plasmonics and metamaterials	MPhil or PhD	Prof. Daniel H. C. Ong
E11	Quantum simulation with a lattice gas of ultracold polar molecules	PhD or MPhil	Prof. Dajun Wang
E12	Electromagnetic resonance properties and behaviours of metal and dielectric nanostructures	PhD	Prof. Jianfang Wang
E13	Biophysics and Quantitative Biology	PhD or MPhil	Prof. Yilin Wu
E14	Vortex dynamics in rotating turbulent convection	MPhil or PhD	Prof. Ke-Qing Xia
E15	Internal wave breaking and its effects on horizontal convection	MPhil or PhD	
E16	Experimental studies of convective turbulence	MPhil or PhD	
E17	Quantum sensing based on nitrogen vacancy centers in diamond	PhD or MPhil	Prof. Kangwei Xia
E18	Experimental study of crystallization at single-particle	PhD	Prof. Lei Xu
E19	Novel interfacial dynamics in ultralow-surface-tension systems	PhD	
E20	Quantum information networks based on NV centers in diamond	PhD or MPhil	Prof. Sen Yang
E21	Quantum sensing of correlated electron systems		

E1. Experimental high energy physics at the Large Hadron Collider (PhD)

(Prof. L Flores Castillo., *castillo@phy.cuhk.edu.hk*, *http://www.phy.cuhk.edu.hk/people/castillo.html*)

Experimental High Energy Physics achieved one of its most cherished goals in recent times on July 4, 2012, when the European Organisation for Nuclear Research (CERN) announced the discovery of the Higgs boson. This achievement required the collaboration of thousands of researchers, the most powerful particle accelerator in history (the Large Hadron Collider, or ***LHC***) and two of the largest and most precise particle detectors ever built. It also led to the awarding of the 2013 Nobel Prize in Physics to Professors Peter Higgs and Francois Englert. During 2014, the LHC will undergo a large upgrade program to increase its center-of-mass energy by about 70%; this large increase will, at the same time, produce a higher number of Higgs particles and open a new mass region, previously unexplored. Students are expected to participate in the preparation work for the analysis of the 2015 data, and to have an active role in physics analyses once the new data-taking period starts. [Two students may be admitted].

Reference :

"Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", Phys. Lett. B716 (2012) 1-29.

E2. Electronic and thermal properties of correlated electron systems under extreme conditions (PhD or MPhil)

(Prof. S. K. Goh, *skgoh@phy.cuhk.edu.hk*, *http://www.phy.cuhk.edu.hk/skgoh/*)

Strongly correlated electron systems (SCES) represent a special class of materials in which the strong Coulomb interaction between electrons plays a prominent role. The strong interaction has resulted in a wide range of fascinating phenomena, including diverse types of magnetism, unconventional superconductivity and metal-insulator transitions. These phenomena are not only of theoretical interest, but are also of growing technological significance.

Our modern laboratory enables the growth of high purity single crystals of topical strongly correlated electron systems and their subsequent investigation under multiple extreme conditions. We are able to examine these crystals at temperatures as low as ~0.01 K, magnetic field up to 14 T and pressures at gigapascal scale (1 gigapascal = 10,000 atm). We will apply powerful probes such as magnetotransport, magnetic susceptibility, heat capacity, and quantum oscillations to study the physics of SCES under these extreme conditions. For our recent results, see references [4-6]. Highly motivated students with a strong background in solid state physics and experimental physics are invited to apply. This programme will involve strong international collaborations.

Therefore, the applicant must also be able to work as part of a team. [One or two students may be admitted.]

References :

1. *N. Mathur et al., "Magnetically mediated superconductivity in heavy fermion compounds", Nature **394**, 39 (1998).*
2. *S. Sachdev and B. Keimer, "Quantum criticality", Physics Today **64**, 29 (2011).*
3. *S. K. Goh et al., "Fermi surface reconstruction in $CeRh_{1-x}Co_xIn_5$", Phys. Rev. Lett. **101**, 056402 (2008).*
4. *S. K. Goh et al., "Ambient pressure structural quantum critical point in the phase diagram of $(Ca_xSr_{1-x})_3Rh_4Sn_{13}$", Phys. Rev. Lett. **114**, 097002 (2015)*
5. *W. C. Yu et al., "Strong coupling superconductivity in the vicinity of the structural quantum critical point in $(Ca_xSr_{1-x})_3Rh_4Sn_{13}$", Phys. Rev. Lett. **115**, 207003 (2015)*
6. *Q. Niu et al., "Quasilinear quantum magnetoresistance in pressure-induced nonsymmorphic superconductor CrAs", Nature Communications (2017) [preprint: arXiv:1612.07480]*

E3. Magnetic fields in star formation (MPhil or PhD)

(Prof. H. B. Li, hbli@phy.cuhk.edu.hk,
http://www.phy.cuhk.edu.hk/people/li-hb.html**)**

Stars and their planets are born when giant clouds of interstellar gas and dust collapse. Astronomers still know very little about the mechanisms behind these processes. For example: why can only a small portion of a cloud collapse into stars? How are protostellar discs formed from clouds? How are disc bipolar outflows launched?

It has been proposed that magnetic fields play a role in all of the aforementioned processes. However, models including magnetic fields are very controversial. The goal of this project is to observationally test these proposals, using telescopes including the Atacama Large Millimeter/submillimeter Array (ALMA; http://www.almaobservatory.org/). [Up to two students may be admitted.]

Reference :

1. *"Magnetic fields play larger role in star formation than previously thought", http://www.cfa.harvard.edu/news/2009/pr200920.html.*
2. *"Birth control for stars", http://news.sciencemag.org/sciencenow/2009/09/10-03.html.*
3. *"Magnetic fields in interstellar clouds", http://www.cfa.harvard.edu/news/2011/su201112.html.*
4. *H.-b. Li, R. Blundell, A. Hedden, J. Kawamura, S. Paine and E. Tong, "Evidence of dynamically important magnetic fields in molecular clouds", MNRAS, 411, 2067 (2011).*
5. *H.-b. Li, M. Houde, S. Lai and T. K. Sridharan, "Tracing turbulent ambipolar diffusion in molecular clouds", ApJ, 718, 905 (2010).*

E4. Magnetic fields in dense molecular phases of spiral galaxies (PhD)

(Prof. H. B. Li, hbli@phy.cuhk.edu.hk,
http://www.phy.cuhk.edu.hk/people/li-hb.html**)**

The role of magnetic fields in spiral galaxies is a mystery still: on one hand, the creation of the magnetic field by MHD dynamo action in the rotating disk is poorly understood. On the other hand, the formation and collapse of molecular clouds, nurseries of stars, may be governed by the strength and topology of galactic magnetic fields.

While galactic field morphologies in diffuse phases are widely mapped, fields in dense molecular phases have been invisible till very recently. The goal is to use the new observational method (Li & Henning 2011) and the new array telescope (ALMA; http://www.almaobservatory.org/) to survey galactic fields in dense media in order to understand the role of magnetic fields in galactic dynamics. [One student may be admitted.]

References :

1. *"Magnetic fields set the stage for the birth of new stars", http://www.sciencedaily.com/releases/2011/11/111116132119.htm.*
2. *"Stellar midwives", http://www.mpg.de/4650664/stellar_midwives?filter_order=L.*
3. *H.-b. Li and T.Henning, "The alignment of molecular cloud magnetic fields with the spiral arms in M33", Nature, 479, 499 (2011), http://arxiv.org/abs/1111.2745.*

E5. Probing stellar birth from the Atacama Desert (MPhil or PhD)

(Prof. H. B. Li, hbli@phy.cuhk.edu.hk,
http://www.phy.cuhk.edu.hk/people/li-hb.html**)**

The so-called "magnetic topology problem", i.e., how does the field topology evolve as molecular clouds form and as clouds contract to form stars, has puzzled astronomers for decades. The goal of this project is to build a polarimeter for the Atacama Submillimeter Telescope Experiment (ASTE). ASTE is a project led by the National Astronomical Observatory of Japan to operate a high precision 10 m submillimeter telescope at a 4860-m site. With the superb atmospheric condition in Atacama, this polarimeter will be able to survey pre-stellar clouds and solve the magnetic topology problem. Magnetic fields in the vicinity of the Galactic central black hole and magnetic fields of extra-galactic clouds are also the fields this project can contribute to.

References :

1. *"Design and Initial Performance of SHARP, a Polarimeter for SHARC-II Camera at the Caltech Submillimeter Observatory", http://arxiv.org/abs/0707.0127.*
2. *ASTE: http://alma.mtk.nao.ac.jp/aste/index_e.html.*
3. *"The Link between Magnetic Fields and Cloud/Star Formation", http://arxiv.org/abs/1404.2024.*

E6. Application of diamond quantum sensing in condense matter physics, materials science, and biomedicine (PhD)
(Prof. Q. Li, 🖃 liquan@phy.cuhk.edu.hk,
🌐 http://www.phy.cuhk.edu.hk/qli/**)**

The nitrogen-vacancy (NV) centers in diamond are extremely sensitive to any environmental parameter that affect its spin states. The atom-like nature and long coherence time at room temperature of the NV centers respectively enable excellent spatial resolution and room temperature sensing experiments, making NV based sensing attractive for a variety of applications in condense matter physics, materials science, and biomedicine. In this project, we aim at developing new sensors and protocols based on diamond NVs, to tackle key problems in nanomagnetism, thermo-plasmonics, energy storage systems, soft matter, as well as mechanics and exogenesis of cellular machinery. Students may focus on one of these directions. [Up to two students may be admitted.]

References :

1. *N. Wang et al.,"Magnetic criticality enhanced hybrid nanodiamond thermometer under ambient conditions", Physical Review X 8, 011042 (2018).*
2. *T. Zhang et al., "Hybrid nanodiamond quantum sensors enabled by volume phase transitions of hydrogels" Nature Communications, 9, 3188 (2018).*

E7. Developing in/ex situ tools for mechanistic study of battery process (PhD)
(Prof. Q. Li, 🖃 liquan@phy.cuhk.edu.hk,
🌐 http://www.phy.cuhk.edu.hk/qli/**)**

The development of battery is like a game played in blackbox. Evolution of the materials themselves (e.g. active electrode material, electrolyte, separators etc.) and their achitectures are closely correlated with the device performance, for example, capacity retention, rate performance, cyclability, and safety. However, monitoring of the battery process is not a simple task, due to the complicated electrochemical reactions during cycling and the anhydrous/anaerobic operation requirement in most cases. In/ex situ characterizations of the battery process are key to understanding of its evolution by simulating real battery conditions. In this project, we will develop in/ex situ protocols to tackle key problems (e.g. capacity fading, thermal runaway, etc.) in designing high performance energy storage devices. [One student may be admitted.]

References :

1. *"Understanding materials challenges for rechargeable ion batteries with in situtransmission electron microscopy", Nature Communications 8, 15806 (2017) doi:10.1038/ncomms15806.*
2. *"Review—Promises and challenges of in situ transmission electron microscopy electrochemical techniques in the studies of lithium ion batteries", Journal of Electrochemical Society, doi: 10.1149/2.1451709jes.*
3. *"Revisiting the origin of cycling enhanced capacity of Fe3O4 based nanostructured electrode for lithium ion batteries", Nano Energy, doi.org/10.1016/j.nanoen.2017.10.001.*

E8. Diamond quantum sensing (2 PhD)
(Prof. R. B. Liu, 🖃 rbliu@phy.cuhk.edu.hk,
🌐 http://www.phy.cuhk.edu.hk/rbliu/**)**

Up to two PhD students are to be admitted to study quantum coherence control using optically detected magnetic resonance (ODMR) of nitrogen-vacancy centers in diamond and its applications in quantum sensing. The project will involve photon detection of spins in diamond under control of microwave pulses and using the ODMR to study condensed matter physics and thermodynamics at nanoscales and to sense biological processes in single live cells. Honesty, strong motivation, and hard working are must. Required is good training in quantum physics, solid-state physics, optics, and experimental physics at the undergraduate level.

References :

1. *K. W. Xia, et al, "Nanometer-precision non-local deformation reconstruction using nanodiamond orientation sensing", arXiv:1901.03235.*
2. *G. Q. Liu, et al. "Quantum coherence control at near 1000 K", arXiv:1810.13089.*
3. *T. Zhang, et al. "Hybrid nanodiamond quantum sensors enabled by volume phase transitions of hydrogels", Nature Communications 9, 3188 (2018).*
4. *N. Wang, et al. "Magnetic criticality enhanced hybrid nanodiamond thermometer under ambient conditions", Physical Review X 8, 011042 (2018).*

E9. In-situ synchrotron characterization of photovoltaic thin films (PhD)
(Prof. X. H. Lu, 🖃 xhlu@phy.cuhk.edu.hk,
🌐 http://app.phy.cuhk.edu.hk/xhlu/**)**

Nowadays, most of the new-generation solar cells are made of semiconducting thin films. Fine-tuning the device fabrication parameters is one of the feasible and promising routes to further push the power conversion efficiency, however, requiring huge amount of time and research efforts. Despite fruitful results on fabrication methodologies and device performance optimization, fundamental studies on crystal structure and morphology, crystal growth and film formation mechanism are still very limited. Careful explorations on these aspects are highly desired, in order to effectively guide future directions of device optimization.The primary goal of this project is to design and carry out in-situ synchrotron characterization experiments for photovoltaic thin films in order to understand the crystallization kinetics, process-structure-performance correlation, and in turn improve the device performance and reproducibility. [Two students may be admitted.]

References :

1. *J. Mai, H. Lu, T.K. Lau, S. Peng, C. Hsu, W. Hua, N. Zhao, X. Xiao, X. Lu, "High Efficiency Ternary Organic Solar Cell with Morphology-Compatible Polymers", J. Mater. Chem. A 5, 11739-11745 (2017).*
2. *X. Lu, H. Hlaing, C-Y Nam, K.G. Yager, C. T. Black and B. M. Ocko, "Molecular Orientation and Performance of Nanoimprinted Polymer-based Blend Thin Film Solar Cells", Chem. Mater. 27, pp.60-66, (2015).*

E10. Topics in plasmonics and metamaterials (MPhil or PhD)
(Prof. D. H. C. Ong, 🖃 *hcong@phy.cuhk.edu.hk*,
🌏 *http://www.phy.cuhk.edu.hk/people/ong.html***)**

Recently, plasmonics and metamaterial have both be named as a new eras after photonics and electronics. They serve as an important platform for studying the fundamentals of light matter interaction by manipulating the electromagnetic waves in an unconventional manner. Their applications include making high efficient light emitting diodes (LEDs) and solar cells, ultrahigh sensitive biosensors, passive and active optical elements for photonic circuitry, optical tweezers, etc. Our group focuses on two projects. The first one studies the interaction between plasmonic systems/metamaterials and quantum dots [1]. We engineer the near-fields around the quantum dots and study how their absorption and emission properties are affected. In particular, we measure the local density of the optical states around one single quantum dot in frequency, momentum, time, and space domains by using several home-built, specially designed microscopes. Its spontaneous emission rate, chirality, photocurrent generation efficiency, etc, are then studied accordingly so that LEDs and solar cells can be implemented eventually. The second project combines plasmonic tweezers and surface enhanced Raman scattering (SERS)/surface plasmon resonance (SPR) sensing in attempt to image single molecules. In principle, this combination produces an analogy of "line of sight" method by placing the target molecules at the right position where they can be seen easily. However, since both the manipulation and the sensing require the precision at the length scale of nanometers, a full knowledge of designing the plasmonic/metamaterial systems to yield suitable hotspots for biosensing, building appropriate characterization tools, generating strong optical force for grabbing the molecules, etc, is essential [2]. These two projects involve extensive collaboration with the theoretical group in Hong Kong University of Science and Technology. [Up to two students may be admitted.]

References :

1. *M. S. Tame et al, "Quantum plasmonics", Nat. Phys. 9, 329 (2013); Z. L. Cao and H. C. Ong, "Determination of coupling rate of light emitter to surface plasmon polaritons supported on nanohole array", Appl. Phys. Lett. 102, 241109 (2013).*
2. *M. L. Juan et al, "Plasmon nano-optical tweezers", Nat. Photonics 5, 349 (2011); C. Y. Chan et al, "Dependence of surface enhanced Raman scattering (SERS) from two-dimensional metallic arrays on hole size", Appl. Phys. Lett. 96, 033014 (2010).*

E11. Quantum simulation with a lattice gas of ultracold polar molecules (PhD or MPhil)
(Prof. D. J. Wang, 🖃 *djwang@phy.cuhk.edu.hk*,
🌏 http://www.phy.cuhk.edu.hk/~djwang/**)**

Ultracold polar molecules can interact via the long-rang and strong dipole-dipole interaction. Theoretically, this has been found to hold great promises in a broad range of applications in quantum simulation and quantum information. However, the experimental investigation on polar molecules is lagging far behind. In this project, starting from a sample of absolute ground-state polar molecules, we will explore ways of producing a degenerate quantum gas of polar molecules. Eventually, these molecules will be loaded into optical lattices for investigating Bose-Hubbard model with true long-range interactions and quantum magnetism models with strong dipolar spin exchange interactions. This project involves advanced knowledge on quantum physics and a variety of experimental techniques. A solid background on quantum mechanics, optics and laser is required. [Two students may be admitted.]

References :

1. *Mingyang Guo et al, "Dipolar collisions of ultracold ground-state Bosonic molecule", Physical Review X, 8, 041044 (2018).*
2. *Xin Ye et al, "Collisions of ultracold NaRb molecules with controlled chemical reactivities", Science Advances 4, eaaq0083 (2018).*
3. *Mingyang Guo et al, "Creation of an ultracold gas of ground-state NaRb molecules", Physical Review Letters 116, 205303 (2016).*
4. *J. L. Bohn, A. M. Rey and J. Ye, "Cold molecules: Progress in quantum engineering of chemistry and quantum matter", Science, 357, 1002-1010, (2017).*

E12. Electromagnetic resonance properties and behaviours of metal and dielectric nanostructures (PhD)
(Prof. J. F. Wang, 🖃 *jfwang@phy.cuhk.edu.hk*,
🌏 *http://www.phy.cuhk.edu.hk/~jfwang/***)**

Metallic and dielectric nanostructures possess interesting electromagnetic resonance properties, which are useful in many technological applications, including optics, optoelectronics, metamaterials, solar energy harvesting, and nanomedicine. Understanding their electromagnetic resonance properties and behaviours is crucial for fully realizing their technological potential. In my group, we will develop methods for the synthesis/fabrication of metal/dielectric nanocrystals and assemble them into superstructures, as well as integrate them with other optically active nanomaterials. New electromagnetic/nanophotonic properties, such as magnetic plasmon resonance, forward light scattering, unidirectional light scattering, and color routing, will be investigated in the obtained structures. The studies will also involve plentiful electrodynamic simulations and simple theoretical analysis based on electromagnetism. The project will require backgrounds and/or interests on optics, physics, nanomaterials. [Two postgraduate students will be admitted.]

E13. Biophysics and Quantitative Biology (PhD or MPhil)
(Prof. Y. L. Wu, 🖃 *ylwu@phy.cuhk.edu.hk*,
🌏 *http://www.phy.cuhk.edu.hk/ylwu/index.html***)**

Life is the most fascinating state of matter. The research in our lab lies at the interface of physics and biology. We seek to understand these questions: How do living things emerge from non-living matter? How do living things function, self-organize, and adapt to the ever-changing environment? And how do living things evolve? To answer these questions we choose to study microbes. Microbes (mostly bacteria) are simple and ubiquitous on the Earth. With novel techniques from physics, biology, chemistry and engineering developed for microbial research, microbes provide tractable systems to uncover the physical principles that govern living matter.

Our current research is focused on cell motility, intercellular communications and population dynamics. Students with either experimental or theoretical background are welcome to apply. Knowledge in optics, microscopy, molecular biology, electrical engineering, or digital image processing is preferred (but NOT required). [One or two students may be admitted.]

References :

1. *To learn more about our current research please visit our lab website: http://www.phy.cuhk.edu.hk/ylwu/index.html*
2. *C. Chen, S. Liu, X. Q. Shi, H. Chaté and Y. L. Wu, "Weak synchronization and large-scale collective oscillation in dense bacterial suspensions", Nature 542: 210-214 (2017).*
3. *"The physics of life", Nature 529, 16-18 (2016). doi:10.1038/529016a.*
4. *H.C. Berg, "Motile behavior of bacteria", Physics Today 53 (1): 24-29 (2000).*

E14. Vortex dynamics in rotating turbulent convection (MPhil or PhD)

(Prof. K. Q. Xia, 🖃 kxia@phy.cuhk.edu.hk,
🌏 http://www.phy.cuhk.edu.hk/turbulence/**)**

Rotating Rayleigh-Bénard (RB) convection is a simplified but relevant model to study the fundamental effects of rotation on convective flows, which is not only of scientific interest but also important to the understanding of related phenomena in the planets and stars. A characteristic flow structure in rotating turbulent convection is the vertically aligned vortex. The changes in its morphology and dynamics are thought to be responsible for the change in heat transport properties and thus determine the multiple transitions among different flow regimes, which is a key issue in the study of rotating turbulent convection. In this project, the geometrical properties and the dynamics of the vortex structures in rotating RB convection will be investigated. Students are expected to use particle image velocimetry (PIV) and laser Doppler velocimetry (LDV) techniques to measure vortex structure, local heat flux and statistical properties of the velocity and vorticity fields, as well as the temperature field. The aim is to understand the mechanism of flow regime transition in rotating thermal convection based on the geometrical and dynamical features of the vortex structures. Students can choose to take either or both experimental and numerical approaches, depending on mutual agreement. [One or two students may be admitted.]

References :

1. *E. M. King, S. Stellmach, J. Noir, U. Hansen and J. M. Aurnou, "Boundary layer control of rotating convection systems", Nature 457, 301-304 (2009).*
2. *B. Favier, L. Silvers and M. Proctor, "Inverse cascade and symmetry breaking in rapidly rotating Boussinesq convection", Phys. Fluids 26, 096605 (2014).*
3. *F. Zhong, R. E. Ecke and V. Steinberg. "Rotating Rayleigh-Bénard convection: asymmetric modes and vortex states", J. Fluid Mech. 249, 135-159 (1993).*
4. *A. Rubio, K. Julien, E. Knobloch and J. Weiss, "Upscale Energy Transfer in Three-Dimensional Rapidly Rotating Turbulent Convection", Phys. Rev. Lett. 112, 144501 (2012).*
5. *S. Sakai, "The horizontal scale of rotating convection in the goestrophic regime", J. Fluid Mech. 333, 85-95 (1997).*

E15. Internal wave breaking and its effects on horizontal convection (MPhil or PhD)

(Prof. K. Q. Xia, 🖃 kxia@phy.cuhk.edu.hk,
🌏 http://www.phy.cuhk.edu.hk/turbulence/**)**

The Atlantic meridional overturning circulation (AMOC) has become a major research focus owing to its significant role in the global climate. A central open question in the study of AMOC is how the deepwater goes through the stratified ocean interior and returns to surface. Although there is growing evidence indicating that internal wave breaking is a principal energy source to drive most of the abyssal mixing, but how internal waves break and transfer energy to small dissipative scales is still unclear and poorly quantified so far. Most importantly, how internal wave induced mixing will affect the distribution and transport ability of the overturning circulation in a global context is still unresolved, the answer of which is crucial for climate modeling and prediction. Horizontal convection is a conceptual model for oceanic circulation. In this project internal wave breaking process in a laboratory horizontal convection apparatus will be investigated. Students will study the influences of internal waves on stratification, vertical mixing, heat transport efficiency and overturning rate in horizontal convection. The results will shed lights on internal wave breaking mechanism and its role in abyssal mixing in the AMOC. Students can choose to take either or both experimental and numerical approaches, depending on mutual agreement. [One or two students may be admitted.]

References :

1. *T. Kuhlbrodt, A. Griesel, M. Montoya, A. Levermann, M. Hofmann and S. Rahmstorf, "On the driving processes of the Atlantic Meridional Overturning Circulation", Rev. Geophys. 45, RG2001 (2007).*
2. *U. Peter, G. Nicklas, F. Thomas and J. Andrew, "The role of the thermohaline circulation in abrupt climate change", Nature 415, 863-869 (2002).*
3. *C. Wunsch and R. Ferrari, "Vertical mixing, energy and the general circulation of the oceans", Annu. Rev. Fluid Mech. 36, 281-314 (2004).*
4. *G. O. Hughes and R. W. Griffiths, "Horizontal convection", Annu. Rev. Fluid Mech. 40, 185-208 (2008).*
5. *L. St. Laurent and C. Garrett, "The role of internal tides in mixing the deep ocean", J. Phys. Oceanogr. 32, 2882-2899 (2002).*
6. *C. Garrett, "Internal tides and ocean mixing", Science 301, 1858-859 (2003).*

E16. Experimental studies of convective turbulence (MPhil or PhD)

(Prof. K. Q. Xia, 🖃 kxia@phy.cuhk.edu.hk,
🌏 http://www.phy.cuhk.edu.hk/turbulence/**)**

Our turbulence research program consists of both experimental investigations and numerical simulations. Students interested in pursuing either MPhil or PhD degrees may be admitted to study topics such as turbulent convections in multilayer fluids and with polymer additives, and flow dynamics and transport in convective turbulence under either confined geometries or rough surface boundaries. Other topics include studies of statistical properties of velocity and temperature fields in thermal turbulence, Lagrangian dynamics of particle; particle dispersion and diffusion in turbulent flows. Students can choose to take either or both experimental and numerical approaches, depending on mutual agreement. [One or two students may be admitted.]

References:

1. *K.-Q. Xia, "Current trends and future directions in turbulent thermal convection", Theor. Appl. Mech. Lett. 3, 052001 (2013).*
2. *Y.-C. Xie and K.-Q. Xia, "Dynamics and flow coupling in two-layer turbulent thermal convection", J. Fluid Mech., 728, R1 (2013).*
3. *S.-D. Huang, M. Kaczorowski, R. Ni, and K.-Q. Xia, "Confinement-Induced Heat-Transport Enhancement in Turbulent Thermal Convection", Phys. Rev. Letts. 111, 104501 (2013).*
4. *P. Wei, R. Ni and K.-Q. Xia, "Enhanced and reduced heat transport in turbulent thermal convection with polymer additives", Phys. Rev. E 86, 016325 (2012).*
5. *C. Sun, Q. Zhou, and K.-Q. Xia, "Cascades of Velocity and Temperature Fluctuations in Buoyancy-Driven Turbulence", Phys. Rev. Letts. 97, 144504 (2006).*
6. *R. Ni, S.-D. Huang and K.-Q. Xia, "Lagrangian acceleration measurements in convective thermal turbulence", J. Fluid Mech. 692, 395 (2012).*
7. *R. Ni, S.-D. Huang and K.-Q. Xia, "Local Energy Dissipation Rate Balances Local Heat Flux in the Center of Turbulent Thermal Convection", Phys. Rev. Letts. 107, 174503 (2011).*

E17. Quantum sensing based on nitrogen vacancy centers in diamond (PhD or MPhil)

(Prof. K. W. Xia, ✉ kwxia@phy.cuhk.edu.hk)

The nitrogen-vacancy (NV) centers in diamond attract attentions due to their unique properties. They have atomic sizes, good photo-stability and their electron and nuclear spins can be optically initialized, coherently manipulated and optically readout in ambient conditions [1, 2]. The encounter of these three separate properties yields a deep and fundamentally new insight: the electron and nuclear spins of NV centers can be explored as magnetic, electric and temperature sensor in extreme precision [3].

In this project, we will coherently control single electron spin of NV centers by means of optically detected magnetic resonance (ODMR) [4], and explore NV centers as a nanoscale quantum sensor to sense different parameters such as magnetic field, electrical field, and temperature in extreme precision. Students will good knowledge in quantum physics and optics are preferred. Interest or backgrounds in programming are good add-ons.

References :

1. *W. Gao, A. Imamoglu, H. Bernien and R. Hanson, "Coherent manipulation, measurement and entanglement of individual solid-state spins using optical fields", Nat. Photon. 9: 363 (2015).*
2. *R. Kolesov, K. Xia, R. Reuter, R. Stöhr, A. Zappe, J. Meijer, P. R. Hemmer and J. Wrachtrup, "Optical detection of a single rare-earth ion in a crystal", Nat. Commun. 3: 1029 (2012).*
3. *Yuzhou Wu, Fedor Jelezko, Martin B Plenio and Tanja Weil, "Diamond quantum devices in biology", Angew. Chem. Int. Ed. 55: 6586 (2016).*
4. *P. Siyushev, K. Xia, R. Reuter, M. Jamali, N. Zhao, N. Yang, C. Duan, N. Kukharchyk, A. D. Wieck, R. Kolesov and J. Wrachtrup, "Coherent properties of single rare-earth spin qubits", Nat. Commun. 5: 3895 (2014).*

E18. Experimental study of crystallization at single-particle level (PhD)

(Prof. L. Xu, ✉ xulei@phy.cuhk.edu.hk,
🌐 http://www.phy.cuhk.edu.hk/~xulei/homepage/)

As one of the most important phase transitions, crystallization plays a crucial role in many different fields in our daily life, including science, technology, and industry. How does the disordered liquid structure transform into the ordered crystalline structure? It has been a focus of research for over one hundred years. Although the classical nucleation theory (CNT) gives a qualitative picture for the process, the microscopic picture at single-particle level remains largely missing. Using colloidal systems, we plan to experimentally tackle this important problem, focusing on the following three fundamental questions in the heterogeneous nucleation crystallization: 1. illustrate its kinetic pathways at single-particle level, and compare with the ones in homogeneous nucleation; 2. explore the influence of the nucleation sites with different sizes and curvatures; 3. study the interaction between different crystal grains, the formation of grain boundary, and the merge of grains. These three topics focus on the very basic problems in crystallization, and will provide invaluable experimental information for crystallization at single-particle level. [One or two PhD students may be admitted.]

References :

1. *P. Tan, N. Xu and L. Xu, "Visualizing kinetic pathways of homogeneous nucleation in colloidal crystallization", Nature Physics 10, 73-79 (2014).*
2. *A. M.Alsayed, M. F. Islam, J. Zhang, P. J. Collings and A.. G. Yodh, "Premelting at defects within bulk colloidal crystals", Science 309, 1207-1210 (2005).*
3. *P. Schall, I. Cohen, D. A. Weitz and F. Spaepen, "Visualization of dislocation dynamics in colloidal crystals", Science 305, 1944-1948 (2004).*

E19. Novel interfacial dynamics in ultralow-surface-tension systems (PhD)

(Prof. L. Xu, ✉ xulei@phy.cuhk.edu.hk,
🌐 http://www.phy.cuhk.edu.hk/~xulei/homepage/)

Novel dynamics may occur in ultralow-surface-tension systems. We would like to focus on the classical problems of droplet coalescence and snap-off in the system. In normal systems, as the connection or breakup point is approached, the Laplace pressure from the surface tension diverges, making the dynamics extremely fast and difficult to probe. In the ultralow-surface- tension system, however, the dynamics could be slowed down by several orders of magnitude. This enables a much better close-up inspection on the dynamics towards singularity, where the most interesting physics takes place. Moreover, because of the significant reduction in the driving force (i.e., the surface tension), completely new physics may emerge: the liquid connection turns highly unstable and could easily form and break; while the previously negligible perturbations or even thermal noise could now become important. These new features may naturally induce surprising outcomes in these classical problems. [One or two PhD students may be admitted.]

References :

1. *G. Chen, P. Tan, S. Chen, J. Huang, W. Wen and L. Xu, Phys. Rev. Lett. 110, 064502 (2013).*
2. *X. Cheng, L. Xu, A. Patterson, H. M. Jaeger and S. R. Nagel, Nature Physics 4, 234 (2008).*

3. *D. G. A. L. Aarts, M. Schmidt and H. N. W. Lekkerkerker, Science 304, 847-850 (2001).*

E20. Quantum information networks based on NV centers in diamond (PhD or MPhil)
(Prof. S. Yang, 🖃 senyang@phy.cuhk.edu.hk,
🌏 http://www.phy.cuhk.edu.hk/senyang/**)**

Quantum communications can provide the ultimate security and quantum computers can provide tremendous potential. Both require the building of the quantum information network. Our group is working on its physical realisation. Recently, we design and demonstrate the world-record-long single optical quantum memory, a key component of the quantum networks[1]. In this project, we will move forward to tackle the heart of the quantum networks: the quantum repeaters, the device that interconnects quantum nodes together. The project will involve designing, optimising and realising quantum algorithms combining RF, microwave and optical technologies. It will also involve advanced techniques of electronics, laser optics, nanophotonics and cryogenics. Unlike the uncertainty nature of quantum physics we are studying, students with determined motivation are preferred. Good training in quantum physics and optics at the undergraduate level is required. Expertise in electronics or programming are good add-ons. [Two students may be admitted.]

References :
1. *S. Yang, et al., "High-fidelity transfer and storage of photon states in a single nuclear spin", Nature Photonics 10, 507-511 (2016).*
2. *H. J. Kimble, "The quantum internet", Nature 453, 1023-1030 (2008).*
3. *B. Hensen, et al., "Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres", Nature 526, 682-686 (2015).*
4. *R. Reichle, et al., "Experimental purification of two-atom entanglement", Nature 443, 838-841 (2006).*

E21. Quantum sensing of correlated electron systems (PhD or MPhil)
(Prof. S. Yang, 🖃 senyang@phy.cuhk.edu.hk,
🌏 http://www.phy.cuhk.edu.hk/senyang/**)**

Strongly correlated systems are one of the most interesting and challenging fields in physics. To understand the physics of quantum phases such as superconductivity and magnetism, a detail measurement on various parameters is needed. We developed a powerful tool of quantum sensing under extreme conditions. In this project, we will apply this tool to study many body physics. It will involve advanced techniques of electronics, laser optics, nanophotonics and cryogenics. Students with determined motivation are preferred. Good training in solid state physics at the undergraduate level is required. Expertise in electronics or fabrication are good add-ons. [Two students may be admitted.]

Reference :
1. *K. Yip, et al., "Quantum sensing of local magnetic field texture in strongly correlated electron systems under extreme conditions", arXiv:1812.10116 (2018).*