

# The Chinese University of Hong Kong

## Division of Physics

### Theoretical Projects

#### 17. Effect of Polymers on Heat Transport in Fluid Flows (MPhil)

(Prof. Ching, E.S.C., Room G5, ☎ (852) 3943 6305,  
E-mail: ching@phy.cuhk.edu.hk)

The reduction of drag by polymer additives in turbulent fluid flows in pipes is a well-known phenomenon. On the other hand, the effect of polymer additives on heat transport is much less studied. Recently, using the simplest model of polymers, we find that the heat transport in a laminar boundary-layer flow is reduced when polymers are added. One student may be admitted to further explore this problem by studying more realistic model of polymers and/or including buoyancy effect.

#### 18. Topics in astrophysics and cosmology (MPhil or PhD)

(Prof. Chu, M.C., Room 106, ☎ (852) 3943 6364,  
E-mail: mcchu@phy.cuhk.edu.hk)

One student may be admitted to work on projects of mutual interest in theoretical astrophysics and cosmology. My current projects include probing physics of the early universe through cosmic microwave background anisotropies [1], dark matter astrophysics and cosmology [2], and neutrino astrophysics [3].

##### References :

1. S.-C. Su and M.-C. Chu, "Is the universe rotating?", *Astrophysical Journal* 703, pp. 354-361 (2009); K.C. Chan and M.-C. Chu, "Cosmological constraints on radion evolution in the universal extra dimension model", *Physical Review D* 77, pp. 063525(1-9) (2008).
2. M.H. Chan and M.-C. Chu, "The existence of sterile neutrino halos in galactic centers as an explanation of the black hole mass - Velocity dispersion relation", *Astrophysical Journal* 692, pp. 212-216 (2009).
3. M.H. Chan and M.-C. Chu, "Decaying sterile neutrinos as a heating source in the Milky Way centre", *Monthly Notices of the Royal Astronomical Society* 389, pp. 297-300 (2008); "Heating of the intergalactic medium by the radiative decay of neutrinos", *Astrophysical Journal* 658, pp. 859-864 (2007).

#### 19. Neutrino oscillation and cosmic ray background (MPhil or PhD)

(Prof. Chu, M.C., Room 106, ☎ (852) 3943 6364)

A new generation of neutrino oscillation experiments has been proposed around the world to measure various neutrino parameters such as the mixing angles. In particular, the value of the  $\theta_{13}$  parameter, which is important for constraining grand unification theories as well as testing leptogenesis models, is yet undetermined from previous experiments. An experiment has been proposed using the Daya Bay Nuclear Reactor<sup>#</sup>, but careful study of the background and event rates is needed for optimizing the detector design. The most important backgrounds for this and other underground experiments are those induced by cosmic rays, and therefore

an underground laboratory at Aberdeen Tunnel has been set up to study these. Students are expected to participate in all aspects of activities related to either the Daya Bay or the Aberdeen Tunnel experiments, including both experimental and theoretical works. [One student may be admitted.]

##### Reference :

# <http://theta13.phy.cuhk.edu.hk/>

#### 20. Topics in the condensed matter physics and quantum information theory (MPhil)

(Prof. Gu, S.J., Room 217, ☎ (852) 3943 6301,  
E-mail: sjgu@phy.cuhk.edu.hk)

One or two students may be admitted to work on any of the following projects in the field of condensed matter physics and quantum information theory. (1) Transport properties in low-dimensional systems; (2) Issues on the role of quantum entanglement in quantum critical phenomena; (3) Issues in the optical lattice. Students are expected to be honest and hard-working with solid background in undergraduate physics and mathematics.

##### References :

1. S.-J. Gu, V.M. Pereira, and N.M.R. Peres, "Scaling study of the metal-insulator transition in one-dimensional Fermion systems", *Physical Review B* 66, pp. 235108(1-7) (2002).
2. Y.-Q. Li, S.-J. Gu, Z.-J. Ying, and U. Eckern, "Exact results of the ground state and excitation properties of a two-component interacting Bose system", *Europhysics Letters* 61, pp. 368-374 (2003).
3. S. Sachdev, "Quantum phase transitions", Cambridge University Press (2000).
4. A. Osterloh, L. Amico, G. Falci, and R. Fazio, "Scaling of entanglement close to a quantum phase transition", *Nature* 416, pp. 608-610 (2002); T.J. Osborne and M.A. Nielsen, "Entanglement in a simple quantum phase transition", *Physical Review A* 66, pp. 032110(1-14) (2002).
5. S.-J. Gu, H.-Q. Lin, and Y.-Q. Li, "Entanglement, quantum phase transition, and scaling in the XXZ chain", *Physical Review A* 68, pp. 042330(1-4) (2003); S.-J. Gu, G.-S. Tian and H.-Q. Lin, "Ground-state entanglement in the XXZ model", *Physical Review A* 71, pp. 052322(1-5) (2005).
6. J. Vidal, G. Palacios, and R. Mosseri, "Entanglement in a second-order quantum phase transition", *Physical Review A* 69, pp. 022107(1-4) (2004); J. Vidal, R. Mosseri and J. Dukelsky, "Entanglement in a first-order quantum phase transition", *Physical Review A* 69, pp. 054101(1-4) (2004).
7. S.-J. Gu, S.-S. Deng, Y.-Q. Li, and H.-Q. Lin, "Entanglement and quantum phase transition in the extended Hubbard model", *Physical Review Letters* 93, pp. 086402(1-4) (2004).
8. S.-J. Gu, C.-P. Sun, and H.-Q. Lin, "Universal role of correlation entropy in critical phenomena", *Journal of Physics A: Mathematical and Theoretical* 41, pp. 025002(1-18) (2008).
9. S.-J. Gu, R. Fan, and H.-Q. Lin, "Ground state of a mixture of two species of fermionic atoms in a one-dimensional optical lattice", *Physical Review B* 76, pp. 125107(1-9) (2007).

## 21. Topics in statistical physics and complex systems (MPhil or PhD)

(Prof. Hui, P.M., Room 209, ☎ (852) 3943 6351,  
E-mail: pmhui@phy.cuhk.edu.hk)

A highly motivated student is sought to join my group. My current interests include (i) competing and evolutionary games in complex networks and their applications (1); (ii) the physics and applications of co-evolving dynamical processes (2,3); and (iii) the interplay between functionality and connectivity in complex networks (3-6). Students with a strong undergraduate physics background and some experience in carrying out numerical computations are encouraged to apply. The students are expected to work hard and be self-motivated. It is my intention to provide a platform for highly motivated students to learn and to develop himself/herself. Only students who take postgraduate studies really seriously need to apply.

### References :

1. D.F. Zheng, H.P. Yin, C.H. Chan, and P.M. Hui, "Cooperative behavior in a model of evolutionary snowdrift games with  $N$ -person interactions", *Europhysics Letters* 80, pp. 18002(1-4) (2007).
2. O. Gräser, C. Xu, and P.M. Hui, "Disconnected-connected network transitions and phase separation driven by co-evolving dynamics", *Europhysics Letters* 87, pp. 38003(1-6) (2009).
3. O. Gräser, C. Xu, and P.M. Hui, "Analytic approach to co-evolving dynamics in complex networks: dissatisfied adaptive snowdrift game", *New Journal of Physics* 13, pp. 083015 (2011).
4. L.-X. Zhong, D.-F. Zheng, B. Zheng, C. Xu, and P.M. Hui, "Networking effects on cooperation in evolutionary snowdrift game", *Europhysics Letters* 76, pp. 724-730 (2006).
5. Z. Zhao, J.P. Calderón, C. Xu, G. Zhao, D. Fenn, D. Sornette, R. Crane, P.M. Hui, and N.F. Johnson, "Effect of social group dynamics on contagion", *Physical Review E* 81, pp.056107 (2010).
6. Y.-C. Ni, H.P. Yin, C. Xu, and P.M. Hui, "Analyzing phase diagrams and phase transitions in networked competing populations", *Eur. Phys. J. B* 80, pp. 233-241 (2011).

## 22. Quantum control of qubit-oscillator models in the ultrastrong coupling regime (MPhil)

(Prof. Law, C.K., Room 307, ☎ (852) 3943 4334,  
E-mail: cklaw@phy.cuhk.edu.hk)

One or two MPhil students may be admitted to work on theoretical investigations of qubit-oscillator interactions in quantum optics. These projects explore novel effects of ultrastrong coupling and issues of quantum control. Students are required to have a strong background in quantum mechanics and electrodynamics. Priority would be given to students experienced in computational physics.

### References :

1. Max T.C. Wong and C.K. Law, "Two-polariton bound states in the Jaynes-Cummings-Hubbard model", *Physical Review A* 83, 055802 (2011).
2. C.K. Law and S.K.Y. Lee, "Dynamic photon-mode selection in Dicke superradiance", *Physical Review A* 75, 033813 (2007).

3. C.K. Law, T.W. Chen, and P.T. Leung, "Jaynes-Cummings model in leaky cavities: An exact pure-state approach", *Physical Review A* 61, 023808 (2000).
4. C.K. Law and J.H. Eberly, "Arbitrary Control of a Quantum Electromagnetic Field", *Physical Review Letters* 76, 1055 (1996).

## 23. Gravitational waves from compact stellar objects (MPhil or PhD)

(Prof. Leung, P.T., Room 204, ☎ (852) 3943 6396,  
E-mail: ptleung@phy.cuhk.edu.hk)

It is generally believed that gravitational waves emitted from violent astrophysical processes in compact stellar objects (e.g. black holes and neutron stars) can be observed in a few years. In addition to providing cogent support for general relativity, gravitational wave detection indeed opens up a new channel for us to infer the internal structure of compact stellar objects far away from our galaxy. In this project, one student will be accepted to study gravitational wave spectra of different compact stellar objects and develop appropriate schemes to infer their physical properties (e.g. mass, size and equation of state). The student is expected to be conversant with standard analytic and numerical techniques.

### References :

1. E.S.C. Ching, P.T. Leung, W.M. Suen, and K. Young, "Quasinormal mode expansion for linearized waves in gravitational systems", *Physical Review Letters* 74, pp. 4588-4591 (1995).
2. P.T. Leung, Y.T. Liu, W.M. Suen, C.Y. Tam, and K. Young, "Quasinormal modes of dirty black holes", *Physical Review Letters* 78, pp. 2894-2897 (1997).
3. L.K. Tsui and P.T. Leung, "Perturbative analysis of universality and individuality in gravitational waves from neutron stars", *Astrophysical Journal* 631, pp. 495-505 (2005).
4. L.K. Tsui and P.T. Leung, "Probing the interior of neutron stars with gravitational Waves", *Physical Review Letters* 95, pp. 151101(1-4) (2005).

## 24. Foundations of quantum computing and quantum physics (2 PhD or MPhil)

(Prof. Liu, R.B., Room 205, ☎ (852) 39436312,  
E-mail: rbliu@phy.cuhk.edu.hk)

Two students are to be admitted to study in theory the physics (not philosophy, mathematics, or engineering) of quantum computing in solid-state systems and fundamental issues in quantum physics. The topics include (1) many-body quantum effects in mesoscopic spin baths, (2) optimal control of quantum systems in mesoscopic environments, (3) nonlinear optical effects in topological insulators, (4) quantum optics in solid-state systems of non-trivial topology, and (5) quantum metrology. Honesty, strong motivation, and hard working are must. Required is good training in quantum mechanics, solid-state physics, optics, and computational physics at the undergraduate level. Priority is given to applications for the PhD program.

### References:

1. N. Zhao, Z. Y. Wang, and R. B. Liu, "Anomalous Decoherence Effect in a Quantum Bath", *Physical Review Letters* 106, 217205 (2011).
2. N. Zhao, J. L. Hu, S. W. Ho, J. T. K. Wan, and R. B. Liu, "Atomic-scale magnetometry of distant nuclear spin

clusters via nitrogen-vacancy spin in diamond, *Nature Nanotechnology* 6, 242 (2011).

3. R. B. Liu, W. Yao, and L. J. Sham, *Quantum computing by optical control of electron spins*, *Advances in Physics* 59, 703-802 (2010).
4. J. Wang, B. F. Zhu, and R. B. Liu, *Second-order nonlinear optical effects of spin currents*, *Physical Review Letters* 104, 256601 (2010).
5. J. Du, X. Rong, N. Zhao, Y. Wang, J. Yang, and R. B. Liu, *Preserving electron spin coherence in solids by optimal dynamical decoupling*, *Nature* 461, 1265-1268 (2009).
6. W. Yang and R. B. Liu, *Universality of Uhrig dynamical decoupling for suppressing qubit pure dephasing and relaxation*, *Physical Review Letters* 101, 180403 (2008).
7. W. Yang and R. B. Liu, *Quantum many-body theory of qubit decoherence in a finite-size spin bath*, *Physical Review B* 78, 085315 (2008).

For more information, visit <http://www.phy.cuhk.edu.hk/rbliu>.

**25. Topics in quantitative finance (MPhil or PhD)**  
**(Prof. Lo, C.F., Room 207, ☎ (852) 3943 6362,**  
**E-mail: cflo@phy.cuhk.edu.hk)**

Quantitative finance is one of the fastest growing areas in the modern banking and corporate world. The main reason behind this phenomenon has been the success of sophisticated quantitative methodologies in helping professionals to manage financial risks. In this project the students will carry out research in various areas in quantitative finance. Possible topics include option pricing, defaultable bond pricing, credit risk analysis, etc. The students are expected to be highly-motivated and hardworking persons who have strong background in mathematical and computational physics. No prior knowledge of finance is required.

**References :**

<http://www.phy.cuhk.edu.hk/~cflo/finance.html>

**26. Topics in theoretical and computational physics (MPhil or PhD)**  
**(Prof. Lo, C.F., Room 207, ☎ (852) 3943 6362)**

Postgraduate students may be admitted to work on the following projects:

- Application of quantum mechanics to materials modeling
- First passage time problems in stochastic modeling
- Quantum entanglement and quantum games

The students are expected to be highly-motivated and hardworking persons who have strong background in undergraduate physics and mathematics.

**References :**

1. K.Y. Wong, C.F. Lo, W.Y. Sham, H.H. Fong, S.K. So, and L.M. Leung, *Theoretical investigation of a blue hydroxyquinoline-based aluminum(III) complex*, *Physics Letters A* 321, pp. 194-198 (2004).
2. M.Y. Yeung, C.F. Lo, and S.K. So, *An ab initio study of carbazole model compounds*, *Journal of Theoretical and Computational Chemistry* 4, pp. 103-115 (2005).
3. C.F. Lo, *Exact solutions of the Fokker-Planck equations with moving boundaries*, *Annals of Physics* 319, pp.326-332 (2005).
4. L.K. Chen, H. Ang, D. Kiang, L.C. Kwek, and C.F. Lo, *Quantum prisoner dilemma under decoherence*, *Physics Letters A* 316, pp. 317-323 (2003).

5. C.F. Lo and D. Kiang, *Quantum oligopoly*, *Europhysics Letters* 64, pp. 592-598 (2003).
6. C.F. Lo and D. Kiang, *Quantum Stackelberg duopoly with incomplete information*, *Physics Letters A* 346, pp. 65-70 (2005).

**27. Topics in soft matter and metamaterials (MPhil)**  
**(Prof. Yu, K.W., Room 206, ☎ (852) 3943 6100,**  
**E-mail: kwyu@phy.cuhk.edu.hk)**

Up to two students may be admitted to work on the following topics: soft metamaterials, nano-optics in graded photonic lattices and plasmonic waveguides, electrokinetics of colloidal and biological cell suspensions, as well as related topics of mutual interest.

A metamaterial is an object that gains its material properties from its structure rather than from the inherent properties that it is composed of. This terminology is particularly relevant to materials which possess properties that are not found in nature. In order for the metamaterial to behave as a homogeneous material accurately described by an effective refractive index, the characteristic sizes must be much smaller than the wavelength of EM fields<sup>#</sup>. The constituent materials can be soft matter, thus giving the advantages of easy fabrication. Metamaterials are promising for a diversity of optical/microwave applications, such as new types of band-pass filters, superlenses, and perfect cloaking.

**Reference :**

- <sup>#</sup> J.P. Huang and K.W. Yu, *Enhanced nonlinear optical responses of materials: Composite effects*, *Physics Reports* 431, pp. 87-172 (2006).

**28. Intense ion beams for high energy density physics and fusion (MPhil)**  
**(Prof. Yu, S.S.L., Room 304, ☎ (852) 3943 6155,**  
**E-mail: ssyu@lbl.gov)**

The understanding of intense ion beams has important implications for new frontiers in high energy density physics and inertial confinement fusion. To achieve the very high intensities required for these applications, we are investigating the transport and acceleration of space-charge-dominated ion beams, the compression of beams in the presence of a neutralizing plasma, as well as the physics of beam-target interaction. These projects are conducted in close collaboration with scientists from the US Virtual National Laboratory for Heavy Ion Fusion Sciences, a joint effort of the Lawrence Berkeley National Laboratory, the Lawrence Livermore National Laboratory, and the Princeton Plasma Physics Laboratory. Students who are interested in research topics involving both theory and experiment and/or large-scale computer simulations are preferred. [Up to two students may be admitted.]

**References :**

1. R.C. Davidson, et al., *Frontiers in high energy density physics - The X-games of contemporary science*, National Academies Press (2003).
2. R.C. Davidson, et al., *Frontiers for discovery in high energy density physics*, prepared by the National Task Force on High Energy Density Physics, July 7, 2004.
3. B.G. Logan, et al., *Recent U.S. advances in ion-beam-driven high energy density physics and heavy ion fusion*; and many other papers in the *Proceedings of the*

16th International Symposium on Heavy Ion Inertial Fusion, published in *Nuclear Instruments and Methods in Physics Research A* (2005).

4. S.S. Yu, et al., "Heavy-ion-fusion-science: summary of US progress", *Nuclear Fusion* 47, pp. 721-727 (2007).

**29. Many-body effects and macroscopic quantum phenomena in quantum gases (MPhil or PhD)**  
**(Prof. Zhou, Q., Room 344, ☎ (852) 3943 1122,**  
**E-mail: qizhou@phy.cuhk.edu.hk)**

One student may be admitted to work on a number of problems on the current frontier of quantum gases. Topics include (1) strongly interacting fermion gas, (2) strongly correlated systems in optical lattices, (3) ultra-cold atoms in synthetic gauge fields and (4) macroscopic quantum phenomena in mixtures of ultra-cold atoms. Deep understanding of simple problems that may lead to conceptually new discoveries will be emphasized in the training. Strong motivation is required. Independent exploration is highly encouraged. Priority is given to applications for the PhD program.

**References :**

1. Qi Zhou and Tin-Lun Ho, "Universal Thermometry for Quantum Simulation", *Phys. Rev. Lett.* 106, 225301 (2011).
2. Qi Zhou, J. V. Porto and S. Das Sarma, "Condensates induced by interband coupling in a double-well lattice", *Phys. Rev. B* 83, 195106 (2011).
3. Qi Zhou and Tin-Lun Ho, "Signature of Quantum Criticality in the Density Profiles of Cold Atom Systems", *Phys. Rev. Lett.* 105, 245702 (2010).
4. Tin-Lun Ho and Qi Zhou, "Obtaining phase diagram and thermodynamic quantities of bulk systems from the densities of trapped gases", *Nature Physics* 6, 131 (2010).

**30. Control of a strong light signal by a weak beam: exploiting optical instabilities in semiconductor microstructures (MPhil)**  
**(Prof. Leung, P.T., Room 204, ☎ (852) 3943 6396,**  
**E-mail: ptleung@phy.cuhk.edu.hk)**

Under certain conditions, two beams propagating along an axis but in opposite directions in a nonlinear medium can undergo directional instabilities: coherent beams of considerable intensity appear spontaneously in off-axis directions, sometimes forming patterns on a transverse plane [1]. In particular, a recent experiment [2] demonstrated that, in a medium of atomic vapors, the direction of an instability-generated, off-axis beam can be changed by shining a very weak control beam at the setup. This is an interesting example of controlling a stronger light signal with a weaker beam. Besides embodying some interesting physics, this result may have practical implications, as a common goal of technical schemes for switching light with light is to lower the threshold control intensity as far as possible.

The present project is a theoretical study of analogous transverse instabilities and light-beam switching in a semiconductor system made up of a quantum well embedded in a microcavity. Despite the analogy, the microscopic physics underlying these instabilities in a semiconductor is very different from that in the atomic vapor system. A microscopic theory of optical nonlinearity in the quantum-well microcavity

has been set up [3] and some first results have been published [4]. Based on the catastrophe theory, we have already worked out classification scheme for these processes. The student joining the project is expected to carry out numerical simulations of the instability-generated processes and the direction-switching by the control beam. The objective is to (i) fully understand all important aspects of these processes; (ii) generalize the study to other instabilities; and (iii) explore other possible applications of the catastrophe theory in physical phenomena.

The study described above is a joint project between Prof. P. T. Leung and Prof. Nai-Hang Kwong in the College of Optical Sciences at The University of Arizona. The student joining the project is expected to have a solid background in undergraduate physics and experience in numerical computations.

**References :**

1. J. B. Geddes, R. A. Indik, J.V. Moloney, and W. J. Firth, *Phys. Rev. A* 50(4), 3471-3485 (1994).
2. A. M. C. Dawes, L. Illing, S. M. Clark, and D. J. Gauthier, *Science* 308, 672 (2005).
3. S. Schumacher, N.H. Kwong and R. Binder, *Phys. Rev. B* 76, 245324 (2007).
4. S. Schumacher, N.H. Kwong and R. Binder, *Phys. Stat. Sol. Rapid Res. Lett.* 3, 10-12 (2009).