PHYS4450 Solid State Physics 2012-13 – 2nd Term
Department of Physics, The Chinese University of Hong Kong

Self-Study plus Presentation – Guidelines
Important Dates:

1 **By 24 January 2013 – INFORM ME of your partner in this self-study plus presentation part of assessment. A team of 2 students will study and report on a topic of their own choice related to solid state physics (SSP). Only in exception case that a student could ask to form a team of one person. The aim is to encourage peer learning.**

2 **(NO LATER THAN) 19 February 2013 (SELECT a topic, collect essential reading materials, have some ideas on what will be focusing in within your chosen topic, and SUBMIT ONE DOCUMENT consisting of the following TWO PARTS for approval: (a) a TWO-A4-page (single-sided) OUTLINE; and (b) a ONE-A4-page (single-sided) ABSTRACT.**

Why Presentations – In preparing for your presentation, you will go through the process of deciding on a possible topic, collecting information/references, digesting the physics, writing an outline and abstract, composing your presentation, rehearsing your talk, and giving an oral presentation. These skills serve to deliver some physics programme learning outcomes, and many of them are transferable skills.

Your OUTLINE (font size = 12) should include your topic and what you will be focusing on in your chosen topic, (in point-form is fine) and a few key references that you have found. It will be good if you can give a time-table on how your team will proceed. Your ABSTRACT should be typed on a separate page and should not exceed 275 words. If you don't know what an abstract is about, pick up a physics journal and read. Many physics journals are available online and in the library. Early submission is encouraged. The outline and abstract will be counted towards the final score.

3 **Final Presentation: Be prepared for a final presentation on 25-26 April 2013 (last two days of Term 2). Each group (of 2 persons) will be assigned a 2×15-minute time slot, plus another 5-8 minutes for questions and answers.**

Rationale: As this is the final semester of your undergraduate studies and the course makes use of knowledge and skills in previous courses, I would like students to take a more active role in their learning. There are so many topics in standard SSP textbooks that we don't have time to cover, and solid state physics (SSP) is an ever-growing subject with new discoveries nearly every year. It is by far the largest branch of physics. To balance the fundamental principles of SSP that we will discuss in our course, students are encouraged to select a topic that they find interesting (or fashionable), search for references, read and digest the references, narrow down into a topic, and **present the topic at the level of a final year undergraduate course**. In addition, through discussions with a group partner, you will gain some experience on peer learning and how to work in a group.

Grades: This takes up 13% of the total grade. [Grade will be assigned according to the written outline/abstract, your presentation file, and the performance in presentation.]

Specifications:

1. You are encouraged to team up with ONE partner to form a group. This will facilitate *peer learning*, i.e., education research showed that when students discuss among themselves, they learn from each other.

2. The final presentation will be approximately 30 minutes in length (my estimate is 15 minutes per student)for a group, with an extra 5-8 minutes for questions and answers. The level of presentation should be that of YOUR PEER, i.e., final year undergraduates. That is to say, you may assume your audience to be typical CUHK Year 3 students. When you prepare your talk, it is useful to have in mind that you are preparing a 30-minute lecture on your selected topic for teaching purpose in PHYS4450. The presentations will be open to all PHYS4450 students.

3. **Scope:** Very flexible! (i) Typically, students pick a topic that they find interesting, look up a few articles and/or journal papers, read and digest them, fill in the basics (physics) to fit to our expected level, and then present the topic. (ii) You may also pick a topic and go deeper into it (encouraged) than what we would do in the course. (iii) Some students may prefer doing some hands-on calculations and simulations. If you can fill in the necessary background of your work and form a complete story, this is perfectly OK. (iv) A mix mode of the above. Most importantly, you should self-learn something that you are interested in. **Warning: You should not select a topic that is out of reach for your background and too broad.** Don't try something too grand and too broad. Pick a narrower topic, go slightly deeper and learn something new is more educational.

4. **Avoid cashing in your work twice!**
   For undergraduates – You may be working on a final year project and/or a Seminar course on a topic related to SSP. That's good. However, in picking your topic for the presentation, you should AVOID TOO MUCH OVERLAP with what you are doing in other courses. After all, you will get another grade for your FYP/Seminar. I am not saying that talking on something related to your FYP is not allowed, but you should make sure that you are not using one work to cash in two grades. For suspicious case, I will consult your FYP supervisor. The same principle holds for topics related to your Seminar course.

5. At this point, don't worry about copyright issues of pictures, etc. (although you SHOULD in other occasions). However, you should **cite the source** of pictures, information, etc. properly in your abstract and presentation. But copying sentences from sources, like any other CUHK courses, is not allowed.

6. **Tips** – A practical way to start is to go to the library or e-Library, browse issues of good physics/science magazines such as *Physics Today*, *Physics World*, *MRS Bulletin* (MRS stands for Materials Research Society), *Wu Li* (in Chinese), and *Scientific American.* There are many good articles introducing the latest developments in physics. There are also good articles (not the short reports) by invited authors in *Science* and *Nature*, including *Nature physics*, *Nature materials*, *Nature photonics* on fashionable topics. These magazines also select the top 10 breakthroughs in science every year. Start from there, you will get some ideas on the frontier topics in SSP. There are references or suggested further reading in these articles for you to dig into the topic. **Another point** is that you should NOT design your talk to review a very broad field. Due to time

limitation, your talk will then be very shallow (too easy). For example, students in previous years talked about "superconductivity" and "magnetic materials". Obviously these choices are TOO BOARD. They can fill a one-semester course. However, if one focuses on the "Landau-Ginzburg theory of superconductors/ferromagnetism" or "realization of Josephson junction arrays", then it sounds more reasonable. Another point – Feel free to come to me/TAs or email me your preliminary ideas. I will be happy to comment on them and give you some references (if I know your topic).

You have complete freedom to select your topic within SSP – but all selected topics need to get an approval (see important dates). Below is a random list of possible (but certainly **NOT restricted to these**) topics.

(0) For Winter 2013, you are NOT allowed to talk about **graphene** (related to 2010 Nobel Physics Prize) and **quasi-crystals** (related to 2011 Nobel Chemistry Prize). We may discuss these cases in lectures and tutorials.

Feel free to suggest your own topic.

(a) Structures: Possible topics are – fill in technical details on how one can determine crystal structures experimentally, the determination of the structure of some interesting materials, e.g., high T_c superconductors, ferroelectric materials, protein, DNA. Structures of liquids and amorphous solids. New light sources (frontier topic) for materials science research.

(b) Lattice Vibrations: Possible topics are – how one can determine the lattice vibration (phonon) dispersion relation experimentally, fill in technical details on full quantum mechanical treatment of lattice vibrations (formalism of phonons), phonon dispersion relations of some real materials, effects of phonons on physical properties, phonon confinement in semiconductor heterostructures and low-dimension systems. Making use of Phonons – phononics (a new topic in recent years) instead of electronics. Interaction with light – polaritons.

(c) Electron in solids: Possible topics are – get into the detail of a method (or methods) in calculating electron energy bands in solids (plane wave expansion, augmented plane waves, idea of pseudo-potential, tight binding method and empirical tight-binding method, density functional theory (Kohn-Sham theorem (Nobel Prize for Kohn)) and its applications, learning how to use existing packages for band calculations, etc.), doing a real band structure calculation, band-gap engineering. Fill in details on experimental methods in determining the Fermi surface. Discussions on real band structures and properties of materials. Learning simplest methods to go beyond single-electron approximation, e.g., Hartree and Hartree Fock approximations, exchange interactions.

(d) Thermal properties: Discussion on thermal properties of some interesting materials, two-level systems and their experimental systems (amorphous materials), thermal properties of quasi-periodic (quasi-crystalline) systems, phononic metamaterails (frontier topic, e.g. cloaking materials for acoustic waves).

(e) Transport properties: Discussion on transport properties of some interesting materials. Semiconductors. Superconductors. Tunnelling in solid state systems. Magneto-transport properties and applications. Applications and formalism of the Boltzmann transport equation. Giant-magnetoresistance (GMR) (Nobel Physics Prize) and its applications. CMR materials. Energy and solid state physics.

(f) Magnetism: Discussion on the origin of magnetism. The setting up of standard model Hamiltonians (classical or quantum) in magnetic systems and the physics (approximations or assumptions). Magnetism and dimensionality. Spin waves and magnons (the analogy of phonons). GMR/CMR materials. Switching dynamics. Monte Carlo simulations of some spin models. Technical stuffs on read-write in magnetic recording. Micro and Nanomagnetism. Laudau theory as applied to magnetism.

(g) Optical properties: Discussion on optical properties of selected interesting materials. Experimental methods of optical measurements (e.g., how to measure the real and imaginary parts of the dielectric constant). Applications of good optical materials. Self-consistent field or random phase approximation of dielectric function (needs some QM background). Effects of dimensionality. Excitons.

The above are more “standard” topics. There are many more rather interesting topics. Some examples are:

(h) Band structure of some wide band gap semiconductors (e.g., GaN). Band structure of carbon nanotubes. Band structure of ferromagnetic metals (Fe, Co, Ni) (not easy). Effective-mass approximation (theory) and k·p theory with applications (semiconductors).

(i) Photonic band gap materials or photonic crystals: properties of EM waves propagating in a periodic dielectric medium. Gaps for EM waves. Applications. Photonic crystal effects in nature. Photonic crystal fibres. Metamaterials (invisible) materials.

(j) Phononic crystals: properties of acoustic wave propagating in a structure with periodic elastic properties. Gaps for sound waves. Applications.

(k) Tunable condensed matter systems: Cold Atoms in optical lattices. How to form an optical lattice using light (laser) waves? Properties. Important problems? Discussion on Hubbard model. Ultracold molecules/chemistry.

(l) NMR and its applications in solids. Probing large molecules. Relaxation times. Relation to quantum information systems.

(m) Percolation. What is it? Its applications to disordered systems. Computer simulations of percolation problems in 2D.

(n) Solid State systems in quantum information. Quantum dots. Defects in diamond.

(o) Conducting polymers (Nobel Chemistry Prize): What are they? How can a polymer show a conductivity comparable to that of copper? Polymers for optical devices.

(p) Liquid crystals (Nobel Physics Prize): What are they? What are the ordering? Applications. Landau theory as applied to liquid crystals.

(q) Quantum Hall effect. Phenomena. Basic ideas of Landau levels. Simple explanation within undergraduate quantum mechanics. Edge states. Topological insulators (what are they? frontier topic).

(r) Scattering of electrons and phonons and their effects. Apply the Fermi golden rule (time dependent perturbation theory in quantum mechanics) to discuss many scattering processes (between electrons and imperfections in solids) and its consequences, e.g., how to calculate the conductivity of a solid.

(s) Setting up second quantized form of a Hamiltonian of a jellium model of metals (with Coulomb interaction). Screening. Green's function approach and Feynman diagrams (advanced topic).

(t) Some spin Hamiltonians and related problems.

(u) Semiconductor heterostructure: These are sandwiches making up of layers of semiconductors. Band structure. Applications. Optical and transport properties. What are the materials used? Lattice mismatch. Band offset problem. Devices.

(v) Quantum dots and wires: When materials are fabricated in the forms of small dots and wires, their properties may be changed. Why? Applications? Density of states effect? Quantum size effects. Small magnetic particles: switching of magnetic moments, applications. Quantum information realization.

(w) Cluster physics: When will a material show bulk properties when we stack up the atoms one by one? How big a cluster of atoms will show bulk properties? How to calculate stable structure given a number of atoms? Molecular dynamics approach. Ways to look for energy minimum in a very high dimensional space. Properties of clusters.

(x) Systems of colloidal particles: belonging to something called soft condensed matter physics. Will particles form an array under suitable conditions? Electrorheological and magnetorheological fluids.

(y) Carbon-60 solids. (Nobel Chemistry Prize)

(z) Spintronics/Magnetic heterostructures: System? Applications? Mechanism? Ideas in exploiting the spin property of electrons as what was did to the charge property in the development of electronic industry? Also related to GMR materials. (frontier topic)

(aa) Superconductivity and Superfluidity: Systems, phenomena, Landau theory, Landau-Ginzburg theory, BCS theory, latest systems showing superconducting behavior. The 2008 new superconductors (with magnetic ions).

(bb) Trapped bosons and fermions (ultra-cold atoms): A very hot topic now. Systems? Why are they interesting? Physics?

(cc) Green's function approach in solid state physics: Definition? Why? Properties? Simple examples?

(dd) Instruments/Microscopy: Ways of probing things with high resolutions. Structures (bulk or surface), Beyond the diffraction limit? Applications to fields beyond physics (e.g., viewing cells), Tunnelling microscopes, Electron microscopes, atomic force microscopes, magnetic force microscopes, etc.

(ee) Plasmonics/Properties of nano-particles: nanooptics, surface plasmonic effects, extraordinary optical transmission, applications (probing molecules), etc. (frontier topics)

(ff) Topological insulators. Strange metals. Exotic phases. Quantum phase transitions.

P.M. Hui
January 2013