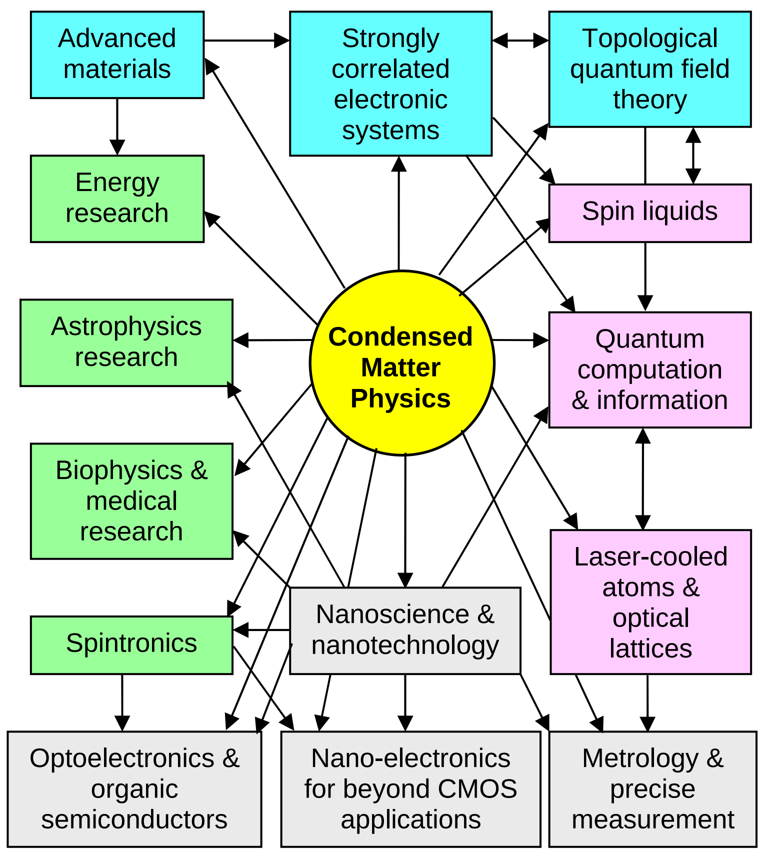
PART I. Introduction

Condensed matter physics is a branch of physics that investigates the physical phenomena associated with various many-body interactions and collective phenomena of matter in the "condensed" (i.e. liquid and solid) phases. The scope of condensed matter physics has evolved and expanded significantly in recently years, from traditional "solid state physics" that largely focuses on effective single-particle pictures in solids and Landau symmetry-breaking theory of phase transitions, to a new arena that encompasses a broad range of topics. Examples of modern condensed matter physics vary from highly interdisciplinary research such as nano- and biophysical sciences, optical lattices and Bose-Einstein condensation in laser-cooled atoms, quantum computation and quantum information technology, to fundamental subjects such as gauge theory, quantum orders and quantum phase transitions, strongly correlated electronic systems, fractional statistics, spin liquids, topological states of matter and topological field theory, *etc.*. In modern condensed matter physics, quantum field theory (QFT) and group theory have played essential roles in the description of many-body interactions, symmetries, and symmetry-breaking. Therefore, QFT complemented by group theory would be the ideal language of choice in the study of modern condensed matter physics. Nonetheless, for this introductory course to condensed matter physics, we will restrict the scope to quantum mechanical descriptions of some of the many-body problems so that the topics to be covered will be mostly in line with the conventional approach. The QFT descriptions of advanced condensed matter physics will be left to Ph223.

Fig. 1: A perspective of the representative fundamental physics topics and various interdisciplinary fields involved in modern condensed matter physics research. The interrelations among different fields are indicated by the arrows. [Adapted from N.-C. Yeh, Bulletin of Association of Asia Pacific Physical Societies (AAPPS), Vol. **18**, No. 2, pg. 11--29 (2008)].



Generally speaking, the foundation of conventional condensed matter physics may be regarded as building on two conceptual cornerstones: the Fermi liquid theory, and the Landau symmetry-breaking theory of phase transitions. The Fermi liquid theory treats the properties of electronic states in solids as perturbations of a ground state consisting of filling the single-particle energy levels. The Landau theory for phase transitions of matter classifies different phases of matter by their symmetries, so that phase transitions are associated with changes in the symmetry of the state of matter. Given the importance of symmetry in conventional condensed matter physics, we will also touch upon some of the applications of group theory to condensed matter physics in this course.

However, we note that the aforementioned cornerstones for conventional condensed matter physics no longer hold when we deal with various emerging phenomena in modern topics of condensed matter physics. For instance, systems of strongly correlated electrons, which include high temperature superconductors, fractional quantum Hall (FQH) states in two-dimensional electron systems (2DES), and the "Luttinger liquid" in one-dimensional conducting systems, all involve properties beyond the perturbative descriptions of conventional Fermi-liquid theory. Similarly, the notion of broken symmetry associated with phase transitions is no longer applicable to the depiction of systems involving topological orders and their phase transitions. Topological field theories, which were originally invented as background-independent theories of quantum gravity and as mathematical tools to derive knot invariants, have found beautiful realizations in various strongly correlated condensed matter states, where they provide a classification of order due to macroscopic quantum entanglement independently of spontaneous symmetry breaking. Well known examples include the fractional quantum Hall (FQH) systems and spin liquids, where transitions among different topological orders can occur without changing the corresponding symmetries. Interestingly, symmetry-protected topological orders do not only exist in strongly correlated systems; they can also be realized in the boundary modes of relatively simple systems that may be described in terms of single-particle physics and conventional electronic bandstructures. Some representative examples of such systems include topological insulators and topological superconductors. These advanced topics are beyond the scope of this introductory course, and will be left to Ph223, "Advanced Condensed Matter Physics".

This course syllabus is structured as follows. We begin in Part II with a quick overview of basic concepts associated with crystalline structures, lattice waves and phonons. In Part III we deal with electronic states and some simplest models for electronic band structures in crystals. Part IV considers perturbative descriptions of the many-body effects of electron-electron interactions in solids. Part V describes the basic concepts of symmetries and group theory, and then considers examples of discrete groups (such as point groups and space groups) that are most relevant to conventional condensed matter physics. However, topics of braid groups, permutation groups and continuous groups that are important in quantum field theory and some of the modern condensed matter physics will not be covered due to time constraints. In Part VI we discuss both macroscopic and microscopic theory of optical properties of solids by elucidating light-matter interactions. Finally, we study basic properties of electrical and thermal transport in solids in Part VII. If time permits, we shall also discuss the effect of high magnetic fields on conducting materials and empirical methods to deduce information about their Fermi surfaces.

There are two reference books ("*Principles of the Theory of Solids*" by J. M. Ziman and "*Solid State Physics*" by N. W. Ashcroft and N. D. Mermin) for this course. At times I'll ask you to study the details of some of the simple topics in the reference books on your own and only mention the key concepts associated with your reading assignments in the class in order to save time for more complex materials and concepts. I'll also hand out class notes from time to time that contain materials beyond or different from what you can find in the reference books. I also plan to give out one problem set approximately every one to two weeks. The due date of each problem set will be explicitly stated on the problem set when it is handed out.