Quantum Hall Effect and Topological Insulators
Syllabus

Instructor:	Di Xiao (dixiao@cmu.edu)	Wean 6418	Phone: 268-2370

Schedule:	TTH, 10:30 – 11:50 in xxx
Office hours:	By appointment.
Textbooks:	There is no textbook available that covers the scientific material associated with this course. Lecture notes and selected journal articles will be placed on the Canvas course site. (Go to canvas.cmu.edu to find our site.)

Course Rationale

Our understanding of semiconductors is based on the band theory: in a crystal the electron energy spectrum splits into bands. Within each band, electrons behave almost like free particles in response to external fields, provided that one replaces the bare electron mass with an effective mass derived from the band dispersion. Despite its simplicity, the band theory has been very successful and has provided the foundation for modern electronics. However, in the past twenty years, it has been made increasingly clear that this semiclassical picture is not complete, and there is much information hidden in the quantum mechanical wave functions. In particular, the topology of the wave function can have a profound effect on material properties. A prime example is the recently discovered topological insulators, which feature gapless edge or surface states that could open up new opportunities for technological applications in spintronics and quantum computing. Although this field is new, topological effects are widespread – about 20% of known materials are topological! This course aims to introduce this exciting development in both condensed matter physics and materials science. Students who complete this course will emerge with a broad understanding and perspective on a topic that is of great scientific and technological importance.

Course Description

This course will introduce students to the topic of topological insulators and related phenomena using the Berry phase a unifying concept. In the first half of the semester, we will cover basic concepts such as Berry phase, Dirac fermions, Hall conductance and its link to topology, and the Hofstadter problem of lattice electrons in a magnetic field. Linear response theory will be discussed in relation to the Hall conductance. In the second half, we will move on to explain topological phases of matter such as Chern insulators and two- and three-dimensional topological insulators. Various techniques to calculate the topological indices will be introduced and connection to real materials will be discussed. Numerical studies of various tight-binding models provide intuitive understandings and will be an essential part of this course.

Course Goals

Upon completion of this course, students should

- Develop a working knowledge of the basics of topological band theory, and be able to calculate topological indices.
- Understand the rationale behind topological material design based on symmetry indicators.
- Connect diverse topological phenomenon such as the quantum Hall effect, the quantum spin Hall effect, magnetoelectric coupling, and Dirac/Weyl materials.

Evaluation of Student Performance

Two of the most critical aspects of a professional science career are communication and problem solving. The evaluative component of this course will emphasize the development of these skills in the students. Two types of assignments will be given:

- Homework Assignments. 3-4 homework assignments will be required. The questions will be based on the topics covered in class and the required readings.
- A term paper on a topic chosen by the students and the instructor.

Late assignments are subject to a penalty of 5% per day.

The class will be delivered in a lecture/discussion format where student participation is expected.

Collaboration Policy

You may discuss the homework assignments, literature reviews and term paper with your classmates; however, the work you submit must clearly be your own. Duplication of answers will result in a zero for both students as well as a referral to the Dean of Students office. Likewise, plagiarism on any assignment will result in a zero for the assignment and a very low grade for the course.

Your success in meeting the goals of this course depends critically on your diligence in doing the assigned readings. The scientific journal articles that I distribute will be difficult reading and, in many cases, will require you to read them 2-3 times in order to fully understand them. I am always happy to answer questions and try to explain things a little better, but you must do the readings!!!

Accommodations for Students with Disabilities

If you have a disability and have an accommodations letter from the Disability Resources office, I encourage you to discuss your accommodations and needs with me as early in the semester as possible. I will work with you to ensure that accommodations are provided as appropriate. If you suspect that you may have a disability and would benefit from accommodations but are not yet registered with the Office of Disability Resources, I encourage you to contact them at access@andrew.cmu.edu.

A Final Note

Take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

We all benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for assistance in getting connected to the support that can help you through challenging periods.