Physics 8820 (Fall 2020)

Topological phenomena in quantum many-body systems

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This is an advanced course for graduate students interested in theoretical physics. We will focus on one special topic in modern condensed matter physics: topological phenomena in quantum many-body systems. We will mostly cover three classes of topological phenomena in condensed matters:

(1) Symmetry-breaking long-range orders, and their topological defects;
(2) Topological insulators, or more generally symmetry protected topological phases with short-range entanglement;
(3) Topological orders, characterized by fractional statistics and long-range entanglement.

If you have any questions about this course, please feel free to email me.

Instructor: Assistant Professor **Yuan-Ming Lu**

Contact Information:

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- Office phone: 614-292-3084
- Office: 2012 Physics Research Building

Course Location: Online. Zoom link TBA, recorded lectures will be available online.

Course Time: Wed. & Fri. 11:10AM - 12:30PM

Office Hour: Online, TBD

Pre-requisites (recommended):

- Quantum Mechanics 2 (Physics 7502), "Modern Quantum Mechanics" by Sakurai, "Principles of Quantum Mechanics" by Shankar or similar textbooks
- Classical and Statistical Physics II (Physics 7602), Landau-Lifschitz, Pathria-Beale, Kardar or similar textbooks
- Knowledge of solid state physics and quantum field theory are preferred but not required.

Textbook:
Lecture notes will be made available on my google site.

References:

- Online lecture notes by Joel Mooore, Sasha Abanov, Ed Witten, Charlie Kane, Chetan Nayak
- An online course ("Topology in condensed matter") organized by Anton Akhmerov, Jay Sau and others.
- 2014 Les Houches Summer School: "Topological aspects of condensed matter physics"
- Prospects in Theoretical Physics 2015 - Princeton Summer School on Condensed Matter Physics: "New Insights Into Quantum Matter"
- Boulder School 2016: "Topological Phases of Quantum Matter"
- *Quantum Field Theory of Many-body Systems: From the Origin of Sound to an Origin of Light and Electrons* by Xiao-Gang Wen (Oxford University Press, 2007)
- *Field Theory in Condensed Matter Physics* by Eduardo Fradkin (Cambridge University Press, 2nd edition, 2013)
- *Condensed Matter Field Theory* by Alexander Altland and Ben Simons (2nd Edition, Cambridge University Press, 2012)

- *Geometry, Topology and Physics (Graduate Student Series in Physics)* by M. Nakahara (CRC Press, 2nd edition, 2003)
- *Modern Condensed Matter Physics* by Steven Girvin and Kun Yang (Cambridge University Press, 2019)
- *Topological insulators and topological superconductors* by Andrei Bernevig and Taylor Hughes (Princeton University Press, 2013)
- *Quantum Field Theory in Condensed Matter Physics* and *Quantum Field Theory in Strongly Correlated Electronic Systems* by Naoto Nagaosa (Springer-Verlag Berlin Heidelberg, 1999)

Assignments:
Typically 1 homework problem will be assigned every week. Since there is no TA, students will be grading each other's homework online and submitted to a Box folder. Solutions will be announced the week after.

Term paper:
A term paper in PRL format (not exceeding 10 pages) is due by 5PM on Dec. 6, 2020 (Sunday). A number of topics will be suggested later. Different students should choose different topics. Each student will give an oral presentation of about 12 mins (+3 mins questions) online during the classes on Dec. 9 and 11.

Grading:
Homework ⟶ 60%; Term paper ⟶ 40%.

Outline of contents :

- Defects in ordered media and homotopy
- Differential forms and topological terms
- Topological terms from Dirac fermions
- Wess-Zumino-Witten terms and deconfined quantum critical points
- Θ-terms and symmetry protected topological (SPT) phases
- Bulk-boundary correspondence and anomalies on the boundary
- Quantized responses of topological phases
- Matrix product states and the classification of 1d short-range entangled (SPT) phases
- Topological superconductors and invertible topological phases
- Berry curvature, 1st Chern class and integer quantum Hall effects
- 2nd Chern class, dimensional reduction and topological insulators
- Invariants and classification of topological bands

- Crystalline topological insulators
- k-space defects, topological semimetals and anomalies
- Floquet topological insulators
- From fermionic topological insulators to bosonic SPT phases
- Symmetry flux, duality and “gauging the symmetry ”
- From SPT phases to topological orders
- Fractional quantum Hall effects and Abelian Chern-Simons theory
- Fractional charge and fractional statistics
- Edge states and how to measure them
- Exactly solvable lattice models for topological orders
- Topological entanglement entropy
- Topological quantum computation
- Constraints on topological phases and Lieb-Schultz-Mattis theorems