SYLLABUS: PHZ 7427, **Phases of Condensed Matter**

Spring 2020

Instructor: Peter Hirschfeld, NPB 2156, interests in superconductivity and strongly interacting electronic systems.

Office Hours : M 8th, F 8th; or just drop in–I will try to make time to discuss if I am free.

Course description: Physics of emergent phenomena, symmetry breaking, topological matter. Introduction to phase transitions and the renormalization group.

Prerequisites: PHZ6426 Solid State I or equivalent course covering fundamentals of 1-electron theory of solids. PHZ7427, Solid State II and PHZ7428, Modern Condensed Matter Physics (Many Body Theory) are desirable but not required.

Required Text: None.

Recommended Text: None (PJH notes will be posted online at start of class.)

Supplementary Resources

1. General references on spontaneous symmetry breaking, soft condensed matter, Landau theory and generalized elasticity theory.
   - P. Chaikin and T. Lubensky. *Principles of Condensed Matter Physics*
   - P.W. Anderson, *Basic Notions of Condensed Matter Physics.*
   - R. Jones, *Soft Condensed Matter.*
   - C. Di Castro and R. Raimondi, *Statistical Mechanics and Applications in Condensed Matter.*
2. Off-diagonal long-range order and condensates
   - J. Annett. *Superconductivity, Superfluids and Condensates.*
   - C.J. Pethick and H. Smith. *Bose-Einstein Condensation in Dilute Gases.*
   - A.J. Leggett, *Quantum Liquids.*
3. Superconductivity
   - M. Tinkham. *Introduction to Superconductivity.*
   - P.G. de Gennes, *Superconductivity of Metals and Alloys.*
   - J.R. Schrieffer, *Theory of Superconductivity.*
4. Liquid Crystals
   - P.G. de Gennes. *The Physics of Liquid Crystals.*
5. Topological Matter
   - J. Asboóth, L. Oroszlány, and A. Pályi, *A Short Course on Topological Insulators*
6. Renormalization Group and Phase Transitions
   - N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*
7. Quantum phase transitions
   - S. Sachdev, *Quantum Phase Transitions*

Required Work: $\sim$ 6 Problem Sets (80%) 1 30-min Journal club presentation (20%).

Course Schedule:

1. *Week 1: Jan. 6-10.* Class does not meet on 10 Jan. – PH in Tallahassee

   Introduction to emergent states in condensed matter physics. Long-range order; discrete and continuous symmetries; spontaneously broken symmetries.

   Reading: Phil Anderson, *More is Different,* Science 177, 393 (1972).

   Video 1: Pines, Coleman, Chaikin: *Emergent Behavior in Quantum Matter*,

   `https://www.learner.org/courses/physics/unit/unit_sci.html?unit=8`

   Video 2: N. Goldenfeld, Emergence and Minimal Models in Condensed Matter Physics and Biology,

   `http://pirsa.org/11100055/`

2. *Week 2: Jan. 13-17.* Examples of broken symmetries: ferro- and antiferromagnets, ferroelectrics, liquid crystals, Bose-Einstein condensation and broken gauge symmetry. Landau theory: 2nd and 1st-order phase transitions. Overview of defects in ordered phases.

3. *Week 3 Jan. 20-24.* Class does not meet Jan. 20 – MLK Day

   Weiss mean field theory of ferromagnet. Breakdown of mean field theory: qualitative aspects of 2D Ising model, Ginzburg criterion.

4. *Week 4: Jan. 27-31.* Spin waves in ferromagnets and antiferromagnets and their observation with neutron scattering. Correlation and response functions, hydrodynamics, Goldstone theorem.

5. *Week 5: Feb. 3-7.* Destruction of phase transitions in low dimensions. 1D Ising model, Mermin Wagner theorem.

6. *Week 6: Feb. 10-14.* Phase transitions in 2D: Berezinskii-Kosteritz-Thouless theory.

7. *Week 7: Feb. 17-21.* Superfluidity in Bose systems. Pairing in superconductors and nuclear matter.

8. *Week 8: Feb. 24-28.* BCS theory, conventional and unconventional superconductivity, Ginzburg-Landau theory (SC in magnetic field). May be skipped if all students are familiar with SC from other courses.

9. *Week 9: Mar. 2-6* UF Spring Break & APS March meeting

10. *Week 10: Mar. 9-13.* Classical phase transitions;Thermodynamic Limit; Phase Boundaries; Analytic Properties of the Free Energy; Phase Transitions; Fluids and Lattice Gases;

11. *Week 11: Mar. 16-20.* Static Scaling Hypothesis. Scaling Laws and Widom scaling; high temperature series expansions.

12. *Week 12: Mar. 23-27.* Kadanoff Block Spins and Renormalization Group

13. *Week 13: Mar. 30-Apr. 3.* Class does not meet Mar. 30–PH at GA Tech, DOE PI meeting.

    RG flows; fixed points; linearised RG and critical exponents; Real Space RG; First-order phase transitions; cross-over behaviour; corrections to scaling; finite size scaling. ϵ-expansion.

14. *Week 14: Apr. 6-10.* No class – PH at UIUC, Northwestern

15. *Week 15: Apr. 13-17.* Topological matter

16. *Week 16: Apr. 20-22.* Topological matter