Collective Effects in Equilibrium and Nonequilibrium Physics

Michael Cross *Spring 2006*

Outline (revised 1 June)

This Special Topics Course will discuss physical concepts and methods that unify the discussion of diverse topics in equilibrium and nonequilibrium, and classical and quantum, systems. The course will be centered around several canonical physical examples, of great importance and interest in their own right. Along the way I hope you will learn about many fascinating topics that might be outside your main area of interest and research, as well as learn or review some of the fundamental ideas of thermodynamics and statistical mechanics.

1. Introduction: When is physics simple?
    - Conserved quantities, symmetries, and phase transitions
    - Thermodynamics (review)
    - Example of symmetries and phase transitions—qualitative discussion of magnetism
2. The simplest magnet: the Ising model
    - Broken symmetry and the phase transition
    - Mean field theory
    - Landau theory
3. Magnets with continuous symmetry (XY model)
    - Spin waves and the Mermin-Wagner theorem
    - Topological defects
    - Kosterlitz-Thouless transition
4. Superfluids and superconductivity
    - What are superfluidity and superconductivity?
    - Connection with magnets?
    - Josephson effect
5. Onsager theory and the fluctuation-dissipation theorem
    - Derivation and discussion
    - Application to nanomechanics and biodetectors

6. Hydrodynamics
    - Hydrodynamics of conserved quantities
    - Hydrodynamics of ordered systems
7. Far from equilibrium
    - What is it?
    - Fluid dynamics and heat convection
    - Rayleigh-Bénard instability
8. Nonlinear theory of patterns near onset
    - Qualitative picture of spatially periodic patterns
    - One dimensional amplitude equations
    - Generalizations to two dimensions
9. Symmetry aspects of nonlinear patterns
    - Phase description
    - Topological defects
10. Pattern formation in biology
    - Turing model
    - Morphogenesis