Physics 569 ESM: Emergent States of Matter

Nigel Goldenfeld

1. Course Information.

The course meets online on Mondays and Wednesdays 2.00-3.20pm. Makeup lectures may be necessary due to the travel schedule of the lecturer, and depending on the class size will be scheduled as needed in evenings or regular working day. However, no travel is anticipated due to the COVID-19 emergency.

My office hour is planned to be at 5.15 pm on Wednesdays. I strongly encourage you to take advantage of this opportunity to talk about physics with me. Feel free to come and talk with me at other times too, although it may be necessary to make an appointment if I am busy or have a meeting in progress.

Office address: 3-113 ESB
Office phone: 3-8027
Email: nigel@uiuc.edu

Office hour: Wednesdays 5.15pm

Web site: http://guava.physics.uiuc.edu/∼nigel/courses/569

The web site will be used to post homework exercises. You also need to sign-in to the course email list so that I can email you announcements when necessary.

2. Grader.

Questions about the grading of homework assignments should be directed to the Graders in the first instance, and then, if necessary to me. The Grader's information is on the class website.

3. Texts.

There is no text for the class, but a number of useful books are recommended. In addition, my notes are available from the class web site. The recommended books are ones that previous students in this course have found helpful, and these are:

(A) General references on spontaneous symmetry breaking, Landau theory and generalized elasticity theory.

- P. Chaikin and T. Lubensky *Principles of Condensed Matter Physics*.
- N. Goldenfeld *Lectures on Phase Transitions and the Renormalization Group*.
- L.H. Ryder *Quantum Field Theory*. There is no quantum field theory *per se* in the course, but some students liked the discussion of symmetry breaking in this book.
- A. Altland and Ben Simons. *Condensed Matter Field Theory*. This is an advanced book, but one of the best to learn about the modern approach to condensed matter theory, with many-body theory done by functional integral techniques, and a clear and readable presentation of many technical issues.
- Mehran Kardar. *Statistical Physics of Fields*. A clear and well-written introduction to modern ways to deal with collective phenomena in condensed matter physics.

(B) 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*

(C) Superconductivity
- M. Tinkham *Introduction to Superconductivity*.

(D) Liquid Crystals
- P.G. de Gennes *The Physics of Liquid Crystals*.

(E) Quantum Hall Effects
- M. Stone *The Quantum Hall Effect*.

(F) Biological emergence
- S. Strogatz *Sync*
- C. R. Woese *On the evolution of cells*, Proc. Natl. Acad. Sci. USA **99**, 8742-7 (2002).

(G) Pattern Formation
- M. Cross and P. Hohenberg *Pattern Formation Outside of Equilibrium*, Reviews of Modern Physics **65**, 851-1112 (1993).

4. Assessment.
There will be several homework assignments, which should be handed in to the 569 box, situated in the corridor between the Loomis Laboratory and the Materials Research Laboratory.

5. Feedback. Please let me know if you have any suggestions or comments about the class. There is no point in waiting until the end of the semester, because by then it is too late for me to act on the suggestion.

6. Preparation.
You are strongly urged to review your quantum mechanics notes, so that you have a working knowledge of *second quantisation*. The first (but not for credit) homework assignment will be a second quantisation worksheet.

Recommended text for 2nd quantisation: Baym *Lectures on Quantum Mechanics*.

TENTATIVE COURSE OUTLINE

Topic 1: Emergent States and Long-Range Order
- Introduction to emergent states. Long-Range Order. Bose-Einstein condensation and Off-Diagonal Long-Range Order.

Topic 2: Vortices in Bose-Einstein Condensates
- Topology, vortices and vortex interactions in rotating condensates.

Topic 3: Quasi-particles in HeII
- Elementary excitations in Helium II. Two-fluid model. λ-transition.

Topic 4: Spontaneous symmetry breaking
- General theory of spontaneous breaking of continuous symmetries. Goldstone's theorem. Response functions. Elementary excitations. Emergent properties.

Topic 5: Superconductivity
- Ginzburg-Landau theory.
- Cooper Pairs.
- BCS theory.
- Electrodynamics of superconductors.
- Flux quantisation.
- Josephson Effects.

Topic 6: Quantum Hall Effects*

- Integer quantum hall effect. Fractional Quantum Effect. Microscopic picture. Ginzburg-Landau theory. Composite particles and fractional statistics.

Topic 7: Liquid Crystals*

- Nematics. Smectics. Smectic A/Superconductivity analogue. Elasticity and hydrodynamics.

Topic 8: Emergence in complex biological systems

- Networks and self-organisation.

Topic 9: Emergent States Far From Equilibrium

- Rayleigh-Benard convection. Bifurcations. Long wavelength description near bifurcations.

Final exam: Please note that a term paper will be substituted for a final exam, and it will be due on this date. More details are on the class website.