Physics 563: Phase Transitions

Nigel Goldenfeld

1. Course information.

The course meets in room 158 of the Loomis Laboratory at 2.00-3.20pm on Mondays and Wednesdays, with makeup lectures at the same time and place on Fridays (by prior arrangement).

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

Office hour: Wednesdays, 4.00pm
I strongly encourage you to visit during this time. I am available at other times too of course, but it may be necessary to make an appointment if I am busy or have a meeting in progress. Email is the best way to reach me. Please do not phone me at home under any circumstances.

Web site

The course has a web site that is used to post materials of extra-curricular interest. In addition, I will sometimes issue announcements concerning the course by email. To facilitate this, please click on the registration link on the web page so that I have your email address. Please do this, even if you are only auditing the course. If you do not register on my web page, you will not receive these occasional but important announcements.

Here is the link:

http://guava.physics.uiuc.edu/∼nigel/courses/563

Questions about the grading of homework assignments should be directed to the Grader in the first instance, and then, if necessary to me.

Grader: Mr. Tom Butler
Office address: 3105 ESB
Office phone: 3-8562
Email: tbutler2@uiuc.edu

Office hour: To be announced.

2. Homework.

It is a vital part of the learning process that you do the homework assignments. The only way to learn physics is to do it; mere attendance at lectures will not suffice, because you will not be able to think for yourself about the material by just listening to me. Confucius has summarised the learning process well:

I hear and I forget
I see and I remember
I do and I understand.

I will attempt to chose homework problems to illustrate, expand upon, or to complement material in the lectures. Wherever possible, they will be in the style of work sheets rather than IQ tests.

Please hand in your completed homework by the specified date; solutions should be deposited in the 563 box, situated in the corridor between the Loomis Laboratory and the Materials Research Laboratory.

3. Term Essay.

Instead of a final exam, you will be required to write a term essay and, depending upon the number of people taking the class, give an "APS-style" ten minute presentation of it at a date to be arranged near the end of term. I will give out a list of suggested topics shortly, although the topic may be anything which interests you and which is related to the topic of phase transitions.

The essays will be distributed on the WWW page of the class; I hope that they will provide you with a useful, concise introduction to many different fields of physics.

4. Books.

This class deals with the way in which matter changes its state, and with the emergence of scaling behaviour in complex systems. When I first gave the course, there was no suitable book, so I wrote one. The lecture notes for this course formed the basis for my book:

- *Lectures on Phase Transitions and the Renormalization Group* (Addison-Wesley, Reading, Ma, 1992).

At my insistence, a reasonably-priced paperback version (ISBN 0-201-55409-7) was simultaneously released with the hard-back version (ISBN 0-201-55408-9), and should be available in the Union text-bookstore or from an online bookstore. I do not intend to deposit my lecture notes in the library, nor distribute worked solutions to problems.

There are a number of other books which you can profitably consult, and with which you may wish to familiarise yourself. These have been placed on reserve in the library:

- D. Amit *Field Theory, The Renormalisation Group and Critical Phenomena.*
- R.J. Baxter *Exactly Solved Models in Statistical Mechanics.*
- J.J. Binney *et al. The Theory of Critical Phenomena.*
- Domb and Green *Phase Transitions and Critical Phenomena, Vols. 1-∞.*
- J. Glimm and A. Jaffe *Quantum Physics: A Functional Integral Point of View.*
- F.J.W. Hahne *Critical Phenomena, Springer Lecture Notes vol. 186.*
- E. Lieb and D. Mattis *Mathematical Physics in One Dimension.*
- S.K. Ma *Modern Theory of Critical Phenomena.*
- A. Patashinskii and V. Pokrovskii *Fluctuation Theory of Phase Transitions.*
- P. Pfeuty and G. Toulouse *Introduction to the Renormalisation Group and Critical Phenomena.*
- D. Ruelle *Statistical Mechanics: Rigorous Results.*

- H. Stanley *Introduction to Phase Transitions and Critical Phenomena.*
- C.J. Thompson *Mathematical Statistical Mechanics.*
- J. Yeomans *Statistical Mechanics of Phase Transitions.*
- J. Zinn-Justin *Quantum Field Theory and Critical Phenomena.*

Two new books have just appeared and I think many of you will like them:

- M. Kardar *Statistical Physics of Fields* and *Statistical Physics of Particles.*

5. Feedback.

If you have any suggestions or comments about the course, please let me know as the term proceeds; don't wait until the end of term. That way, I can be responsive to your suggestion.

Course Outline

This is a tentative outline only. Some topics will be treated in detail, others will be treated cursorily or only if time permits.

§1. **Introduction.**
Preamble; examples of scaling; overview of course.

§2. **Review of Statistical Mechanics.**
Thermodynamic Limit; Phase Boundaries; Ising Model; Analytic Properties of the Free Energy; Phase Transitions; Fluids and Lattice Gases.

§3. **Transfer Matrix and One-Dimensional Systems.**
Eigenvalue degeneracy, Frobenius-Perron Theorem, Low temperature expansion.

§4. **Van der Waals Fluid.**

§5. **Weiss Ferromagnet.**

§6. **Common Features of Mean Field Theories: Landau Theory.**
Spatial variations; fluctuations and Ginzburg criterion.

§7. **The Static Scaling Hypothesis**
Scaling Laws and Widom scaling; high temperature series expansions.

§8. **Kadanoff Block Spins.**

§9. **Renormalisation Group: general concepts.**
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.

§10. **Critical Phenomena near $d = 4$ and the O(n) Model**
Differential RG recursion relations; ϵ-expansion; $1/n$-expansion; O(n) model for $T < T_c$ and Goldstone's Theorem; Kosterlitz-Thouless transition.

§11. **Dynamic Critical Phenomena.**
Van Hove theory; dynamic scaling hypothesis; RG approach.

§12. **Random Systems.**
Harris criterion; replica method.

§13. **Novel Applications of the Renormalisation Group.**
Asymptotic behaviour of partial differential equations; interface dynamics; fully-developed turbulence.