Physics 848 (D. Stroud): Term Project Assignment

As mentioned previously, one of the assignments in this course is a term project. In general, I am very flexible about possible projects, and am likely to accept any reasonable proposal from a student. The project can consist of a paper describing the statistical physics of some interacting system. It can involve library research, or your own numerical simulations, or some combination of the two. I do not expect any original research, but I would like to see that you have gained some understanding of some such problem.

In either case, you should pick a narrow topic - if library research, a clear understanding of one or two papers, or simulations on a single, narrowly defined model, would be sufficient. As I said before, the project can be presented either as a talk or a written paper. The project can be one a numerical project of some kind (e. g. Monte Carlo study of some model Hamiltonian, molecular dynamics study, a study of a percolation model, etc.) I More than one can choose the same subject, in which case there should be some division of labor - e. g., one person gives a talk, the other does a write-up.

For the term paper, I would anticipate a write-up of around 10-15 double-spaced pages (preferably typed). If your paper consists of simulations, of course much of your write-up (or talk) would consist of your numerical results. You should work independently, although of course you can certainly talk and exchange ideas with one another.

I would like a brief outline (one page or less) of what you plan to do by Monday, November 14, and would like to receive the term papers themselves by Friday, December 3 at 5PM. I would prefer if you would check with me (email is fine) before you choose a topic; I will try to make sure not too many people pick the same topic, and also that the topic is suitably narrow.

The following is a preliminary and incomplete list of some possible topics This is just to get you started thinking along these channels. I will try to provide a more complete list, with references, soon.

1. Kosterlitz-Thouless transition and the XY model in two dimensions. References: J. M. Kosterlitz and D. Thouless, J. Phys. **C6**, 1181 (1973) and **C7**, 1046, 1974. For applications, see D. Nelson in **Phase Transitions and Critical Phenomena**, vol. 7 (C. Domb and M. Green, eds.), Academic, New York, 1983. This could also make a good numerical project.

2. Phase transitions in liquid crystals. See, e. g., *Principles of Condensed Matter Physics*, P. M. Chaikin and T. C. Lubensky (Cambridge U. P., 1995), pp. 58-71 and elsewhere in that book. There are other references which may be better than this.

3. Percolation as a phase transition. See, e. g., C. M. Fortuin and P. W. Kasteleyn, *Physica* **57**, 536 (1972); S. Kirkpatrick, Rev. Mod. Phys. **45**, 573 (1973).

4. Molecular dynamics simulations of a Lennard-Jones fluid. Reference: Hansen and McDonald *Theory of Simple Liquids*.

5. The Percus-Yevick approximation and related integral equations for the structure factor of a simple liquid.

6. Statistical mechanics of traffic jams. Ref: D. Helbing, Rev. Mod. Phys. **73**, 1067 (2001).

7. Disordered spin systems and spin glasses. See, e. g., K. Binder and A. P. Young, Rev. Mod. Phys. **58**, 801 (1986).

8. Feynman and Feynman-Cohen model for the excitation spectrum of ^{4}He. Reference: Feynman and Cohen, Phys. Rev. **102**, 1189 (1956) and references therein; K. Huang, pp. 325-38, and references therein.

9. Statistical mechanics of freezing. E. g., T. V. Ramakrishnan and M. Yussouff, Phys. Rev. **B19**, 2775 (1979).

10. Fully frustrated XY model in two dimensions. Ref.: S. Teitel and C. Jayaprakash, Phys. Rev. **B27**, 598 (1983).

11. Statistical mechanics of ferrofluids or electrorheological fluids. Reference: T. C. Halsey, Science **258**, 761 (1992); Scientific American **269**, 58 (1992).

12. Laughlin model for the two-dimensional electron gas in a strong magnetic field. Ref.: R. B. Laughlin, Phys. Rev. Lett. **50**, 1395 (1983) and references cited therein. (Difficult topic.)

13. Colloidal crystals and colloidal crystallization. References: Trau *et al*, Science **272**, 5262 (1996); John Maddox, Nature **378**, 231 (1995) and references therein.

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14. Renormalization-group treatments of specific phase transitions See, for example, Chaikin and Lubensky, or N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group* (Addison-Wesley, Reading, MA, 1992). (Difficult.)

15. High-temperature series expansions and the Pade approximant method.

16. Exactly soluble models and results in statistical mechanics. E. g. 2D Ising Model (cf. Huang), Mermin-Wagner theorem (cf. N. D. Mermin and H. Wagner, Phys. Rev. Lett. **17**, 1133 (1966).

17. Approximate integral equations and other analytical approximations in the theory of liquids. You can find these discussed in various chapters of Hansen and McDonald, *Theory of Simple Liquids*.

18. Advanced or novel Monte Carlo methods with applications. Some references" A. M. Ferrenberg and R. H. Swendsen, Phys. Rev. Lett. **61**, 2635 (1988); **63**, 1195 (1989); J. Lee and J. M. Kosterlitz, Phys. Rev. Lett. **65**, 137 (1990).

19. Bose-Einstein condensation in interacting gases at low temperatures. Refs.: M. H. Anderson*et al*, Science **269**, 198 (1995); Jin *et al*, Phys. Rev. Lett. **77**, 420 (1996). (There is a whole course on this subject; still, if you would like to do a term project on this for p848, this will be OK, provided you do not use the same project for credit in any other course.)

20. Superfluid ^{3}He A and B. See, for example, O. Lounasmaa, Scientific American **262**,m 104 (1990; J. Tilley, Contemp. Phys. **32**, 339 (1991) and references therein.

21. Antiferromagnetic Heisenberg model in two dimensions; RVB theory. Ref.: A. V. Chubukov, Phys. Rev. **B49**, 11919 (1994) and references cited therein.

22. Statistical physics of sandpiles. Ref.: S. R. Nagel, Reviews of Modern Physics **64**, 321 (1992).

23. Statistical models of growth and aggregation. See, e. g., P. Meakin, Phys. Rev. Lett. **51**, 1119 (1983); D. A. Weitz and M. Oliveria, Phys. Rev. Lett. **52**, ‘433 (1984).

24. Monte Carlo solution of, e. g., Ising model in 3D, XY model in two or three dimensions, frustrated XY model.

25. The liquid-glass transition in statistical physics. See, e. g., E. Leutheusser, Phys. Rev. **A29**, 2765 (1984).

26. Statistical mechanics of protein folding; possibly other problems in biophysics. E. g., J. Wang *et al*, Phys. Rev. Lett. **76**, 4861 (1996).

27. Critical phenomena near the phase transition between a normal metal and a superconductor. (This is a difficult topic, unless you already have some background in superconductivity.)

28. Order-disorder transitions in binary alloys. The classic example here is the $\beta - \beta'$ transition in brass ($Cu_{0.5}Zn_{0.5}$), but there are many others. I will be happy to provide references on request.

29. Phase transition-like phenomena in networks. Reference: D. J. Watts and S. Strogatz, Nature **393**, 440 (1998).

As you can see, the possibilities are very broad. In many cases, I will not be able to provide a lot of help, but I welcome suggestions from you for any exciting problem in statistical physics. As I said, I will try to provide references for many of the above, and some additional topics, in the next few days.