Course on "Advanced Statistical Physics"

School of Nano Science, for Research in Fundamental Sciences (IPM), Tehran, Iran
Spring Semester 2016 (1394-1395)

Lecturer: Ali Naji (School of Physics, IPM)

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- **Time:**
  Tuesdays, 9:00 - 10:15 and 11:00 - 12:15 (three-unit course)
  Starting from Sunday March 27, 2016 (Farvardin 8, 1395)

- **Place:**
  Classroom C, 2nd floor, Farmanieh Central Building
  Institute for Research in Fundamental Sciences (IPM), Farmanieh Campus,
  No. 70, Lavasani St., Tehran, Iran

- **Website: http://physics.ipm.ac.ir/~naji/particles_SS2016.html**

- **Tutorial sessions:**
  Tuesdays, 13:30 - 15:00, Classroom C, by Dr. Bahman Roostaei (IPM)

- **Final grade:**
  The final grade will be determined based on a number of factors including **homework assignments**, active contribution to **tutorial sessions** and a **final exam**. The students may also **write** and **present** a term essay for **extra credit** on a subject they select from a list of suggested term-essay topics (see below for further details).

- **Intended audience and pre-requisites:**
  This course is intended for Ph.D. students in Nano Science and related fields such as Condensed Matter Physics, Soft Matter, Biological and Statistical Physics. It may nevertheless be useful for and attended by advanced M.Sc/B.Sc. students with an elementary knowledge of **thermodynamics** & **statistical mechanics** (comparable to the level of standard B.Sc./M.Sc. textbooks in Physics). All students who sign up for the course will be expected to attend the lectures and tutorial sessions on a regular basis and do the homework assignments. Auditing students will be required, as a form of contribution to the class, to give an **oral presentation** at the end of the course on a subject they select from a list of suggested term-essay topics.

- **Scope & summary:**
  I shall begin with an in-depth review of the foundations of **equilibrium statistical physics** for closed (and quasi-closed) many-particle systems and the pursuant micro-canonical distribution from which one can derive the well-known thermodynamic relations as well as the canonical and grand-canonical distributions when the system is not closed but, together with its surrounding environment, can be considered as part of a larger closed system. These results will be generalized to equilibrium statistical physics of quantum identical (Bose and Fermi) particles. After discussing several examples of ideal (non-interacting) systems in both classical and quantum cases, I shall turn to the theory of interacting classical fluids and discuss how inter-particle interactions can be accounted for using virial expansion and, if time permits, other advanced methods of the liquid-state theory. I shall then discuss the theory of Coulomb

(charged) fluids and give an overview of their modern applications in soft matter and biological physics and the recent advances made in their studies over the last several years. The second part of the course will be devoted to **equilibrium phase transitions and critical phenomena** with topics ranging from Ising model, Landau mean-field theory and Gaussian fluctuations, Widom scaling and the real-space renormalization group techniques to other modern notions such as ergodicity breaking and continuous and discrete symmetry breaking. I shall also devote some time to discuss a few basic subjects on **non-equilibrium statistical physics** of particles, including kinetic theory of many-particle systems, linear response theory and the fluctuation-dissipation theorem, and stochastic dynamics of Brownian particles as governed by Langevin and (Smoluchowski-) Fokker-Planck equations. The lectures in each of the main areas covered in the course will be supplemented by slide-presentation sessions, illustrating real-world examples, key experimental and computational evidence as well as modern applications and recent advances made in the study of the topics in question. The homework assignments shall be designed in such a way as to complement the subjects discussed in the lectures. **A more comprehensive and updated list of subjects covered in this course is available at the course website.**

- **Homework, term essay & final exam:**
  Homework assignments will be given on a regular basis and in the form of problem sets that can be dowloaded from the course website. The homework solutions must be typed in English using LaTeX. The source tex/figure files and a pdf output, carefully proof-read for any typos and/or grammatical errors, must be submitted via email. The **homework solutions** will be graded, making altogether 40% of the final score with the rest coming from the **final exam** (40%) and an evaluation by the tutor of the active participation and contribution of the students to the discussions in the **tutorial sessions** (20%). The students who sign up for the course may also **write** and **present** a term essay for **extra credit** on a subject they select from a list of suggested term-essay topics; the list along with further instructions will be made available on the course website in due course. Students can propose other topics for their term essay and they need to confirm their choice of the term-essay subject with me beforehand. Term essays must be prepared in the form of standard scientific reports or review articles using a LaTeX template and other specifications to be circulated with the list of topics. The source tex/figure files and a pdf output of the term essay must be submitted via email before a deadline that will be announced later. Auditing students will be required, as a form of contribution to the class, to give a **short seminar** during or at the end of the course on a subject they select from the list of suggested term-essay topics.

- **References:**
  There are many valuable books covering the topics of this course at different levels. I will not follow any particular textbook in general and rely mostly on self-designed lectures. For further reading, I can recommend (any of) the textbooks listed below.

LIST OF REFERENCES BY TOPIC

Equilibrium Statistical Physics:

Suggested textbooks: (in reverse chronological order)

- L. Reichl, *A Modern Course in Statistical Physics; 3rd edition* (2009)
- M. Kardar, *Statistical Physics of Particles* (2007)
- M. Plischke & B. Bergerson, *Equilibrium Statistical Physics; 3rd edition* (2006)
- M. LeBellac, F. Mortessagne & G.G. Batrouni, *Equilibrium & Non-Equilibrium Thermodynamics* (2004)

Equilibrium phase transitions and critical phenomena:

Suggested textbooks: (in reverse chronological order)

- R.K. Pathria, *Statistical Mechanics, 3rd edition* (2011)
- D.I. Uzunov, *Introduction to the Theory of Critical Phenomena* (2010)
- H. Nishimori & G. Ortiz, *Elements of Phase Transitions & Critical Phenomena* (2010)
- G. Mussardo, *Statistical Field Theory* (2010)
- L. Reichl, *A Modern Course in Statistical Physics; 3rd* (2009) *& 2nd* (1998) *editions*
- M. Kardar, *Statistical Physics of Fields* (2007)
- M. Plischke & B. Bergerson, *Equilibrium Statistical Physics; 3rd edition* (2006)
- M. LeBellac, F. Mortessagne & G.G. Batrouni, *Equilibrium & Non-Equilibrium Thermodynamics* (2004)
- W.D. McComb, *Renormalization Methods: A Guide for Beginners* (2004)
- P.M. Chaikin & T.C. Lubensky, *Principles of Condensed Matter Physics* (1995)
- J.J. Binney et al., *The Theory of Critical Phenomena* (1992)
- J. Yeomans, *Statistical Mechanics of Phase Transitions* (1992)
- N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group* (1992)
- K. Huang, *Statistical Mechanics; 2nd edition* (1987)
- H.E. Stanley, *Introduction to Phase Transitions & Critical Phenomena* (1971)

Non-equilibrium Statistical Physics:

Suggested textbooks: (in reverse chronological order)

- W.T. Coffey & Y.P. Kalmykov, *The Langevin Equation; 3rd edition* (2012)
- C. Gardiner, *Stochastic Methods, 4th edition* (2009)
- L. Reichl, *A Modern Course in Statistical Physics; 3rd* (2009) *& 2nd* (1998) *editions*
- M. Kardar, *Statistical Physics of Particles* (2007)
- N.G. Van Kampen, *Stochastic Processes in Physics and Chemistry, 3rd edition* (2007)
- M. LeBellac, F. Mortessagne & G.G. Batrouni, *Equilibrium & Non-Equilibrium Thermodynamics* (2004)
- H. Risken, *The Fokker-Planck Equation, 2nd edition* (1996)