SFT-2018
Lectures on Statistical Field Theories
Galileo Galilei Institute
Florence, 5-16 February 2018

Program of lectures

Andrea Cappelli
Introduction to Topological States of Matter (6h)

Overview:
- Introduction: topological excitations and topological phases;
- Berry phase in two-level systems and Dirac monopole;
- Quantum Hall effect: Berry phase and chiral anomaly;
- Haldane model of Chern Insulator;
- Introduction to the tenfold classification of topological states.

Prerequisites:
- Landau levels (see, e.g.: Landau, Lifshitz, Quantum Mechanics);
- Homotopy groups (see, e.g.: Nakahara, Geometry, Topology and Physics, Cap. 4).

References:
- X. G. Wen, Quantum Field Theory of Many-body Systems, Oxford Univ. Press, Oxford (2007);
- E. Fradkin, Field Theories of Condensed Matter Physics, Cambridge University Press (2013);
- M. Franz and L. Molenkamp Eds., Topological Insulators, Elsevier, Amsterdam (2013).

Marcello Dalmonte
Topological phases in cold-atom systems (6h)

The aim of these lectures is to illustrate the potential of cold atoms systems to investigate paradigmatic phenomena in topological matter. The focus will be on two examples, the Haldane phase and topological superconductivity. Beyond theoretical considerations, state of the art quantum engineering and probing methods will be discussed.

Part I) the Haldane chain:
- sigma model and Haldane conjecture;
- non-local order parameters (strings) and Kennedy-Tasaki transformation;
- discussion of numerical evidences;
- possible cold atom incarnations of the Haldane phase and measurements of non local order parameters.

Part II) topological superconductors:
- the Kitaev *p*-wave superconductor and Majorana zero modes;
- cold atom implementation of spin-orbit couplings and classical gauge fields;
- beyond single-particle physics: interacting models with Majorana zero modes.

If time allows, I will also present some recent ideas on entanglement measurements in cold atoms systems.

Several references will be given over the course of the lectures. Here are four general suggested readings:
— E. Fradkin, Field theories of condensed matter systems
— B. A. Bernevig, Topological insulators and topological superconductors
— J. Dalibard et al., Rev. Mod. Phys. 83, 1523 (2011)

Satya Majumdar
Introduction to Random Matrix Theory and its various applications (10h)

Outline of the course:
1) Brief historical introduction to RMT: applications. Discussion of basic properties of matrices, different random matrix ensembles, rotationally invariant ensembles, Gaussian ensemble, etc.
2) Gaussian ensembles: derivation of the joint probability distribution of eigenvalues, starting from the joint distribution of matrix entries.
3) Analysis of the spectral properties of eigenvalues: given the joint distribution of eigenvalues, how to calculate various observables such as:
(i) Average density of eigenvalues ----Wigner semi-circle law;
(ii) Counting statistics, spacings between eigenvalues etc.;
(iii) Distribution of the extreme (maximum or minimum eigenvalues).
4) Two complementray approaches to study spectral statistics:
a) Large N (for an NxN matrix) method by the Coulomb gas approach: saddle point method;
b) finite N method: for Gaussian unitary ensemble: orthogonal polynomial method: Connection to the quantum mechanics problem of free fermions in a trap at zero temperature and application to cold atom physics.
5) Tracy-Widom distribution: probability distribution of the top eigenvalue. Its appearence in a large number of problems, universality and an associated third order phase transition.
6) Perspectives, summary and other applications.

Suggested readings/references:
- “Random matrice”, the book by M. L. Mehta
- “Log-gases and Random matrices”, the book by P.J. Forrester
- “Introduction to Random Matrices - Theory and Practice", G. Livan, M. Novaes, P. Vivo: arXiv: 1712.07903
- S.N. Majumdar, Les Houches lecture notes (Complex systems, 2006), arXiv/cond-mat/0701193
- “Extreme Value statistics of correlated random variables”, lecture notes for the GGI (Florence, 2014) workshop by S.N. Majumdar (notes taken by a student A. Pal), arXiv: 1406.6768
- S.N. Majumdar, a book chapter in “Handbook of random matrix theory” ed. by G. Akemann et.al. ArXiv: 1005.4515
- A recent review: S.N. Majumdar and G. Schehr, “Top eigenvalue of a random matrix: large deviations and third order phase transition”, J. Stat. Mech. P01012 (2014), arXiv: 1311.0580
- Review article by Y. V. Fyodorov, arXiv: 0412017
- Review “Random matrix theory of quantum transport” by C.W.J. Beenakker, Rev. of Mod. Phys. 69, 731 (1997).

See also two recent popular articles:
- “Equivalence Principle” by M. Buchanan, Nature Phys. 10, 543 (2014) http://www.nature.com/nphys/journal/v10/n8/full/nphys3064.html?WT.ec_id=NPHYS-201408
- “At the far ends of a new universal law” by N. Wolchover, Quanta magazine (October, 2014) https://www.quantamagazine.org/20141015-at-the-far-ends-of-a-new-universal-law/

Markus Müller
Many-body localization (8h)

Many-body localization is the surprising phenomenon of non-thermalization and non-ergodicity in a thermodynamically large (but closed) interacting quantum system. It occurs, e.g., in cold atoms, quantum magnets, or arrays of superconductors if quantum fluctuations and chaos-producing resonances are sufficiently suppressed by quenched disorder.
We will review the rich phenomenology and the conceptual interest of systems that are fully or nearly localized. We then study perturbative, but quantitative approaches to well localized phases. As we will see they are ultimately limited by various types of rare events, that, however, control transport and long time dynamics in badly conducting systems. Despite the challenges those rare events introduce, many-body localization can be proved to exist under certain circumstances. We will review the instructive essentials of the proof and the physics behind its failure in higher dimensions. Finally, we will build on those ideas to study real space renormalization schemes and use them to analyze the very unusual nature of the dynamical delocalization transition.

Suggested readings:
- R. Nandkishore and D. Huse, “Many-Body Localization and Thermalization in Quantum Statistical Mechanics”, Annual Review of Condensed Matter Physics, Vol. 6: 15-38 (2015)
http://www.annualreviews.org/doi/pdf/10.1146/annurev-conmatphys-031214-014726
- D. A. Abanin and Z. Papic, “Recent progress in many-body localization”, Ann. Phys. (Berlin) 529, No. 7, 1700169 (2017) - DOI 10.1002/andp.201700169

Prerequisites:
- Many-body quantum mechanics, second quantization;
- elementary knowledge of Green's functions.

Herbert Spohn
The Kardar-Parisi-Zhang Universalirty class (8h)

My lectures have the Chapters:
1) Dynamics of interfaces (stable/metastable);
2) Exact solutions;
3) Universality;
4) Other systems in the KPZ class.

There is a huge literature on the subject, including the still readable introductory text:
- A.L. Barabasi and H.E. Stanley, Fractal Concepts in Surface Growth, Cambridge University Press, 1995,
and the textbook:
- M. Kardar, Statistical Mechanics of Fields, Chapter 10, Cambridge University Press, 2007.

I have written two more recent lecture notes with a somewhat distinct focus:
- H. Spohn, Fluctuating hydrodynamics approach to equilibrium time correlations for anharmonic chains, Springer Lecture Notes in Physics, Volume 921, pp. 107--158, Thermal transport in low dimensions: from statistical physics to nanoscale heat transfer, ed. S. Lepri (2016).
- H. Spohn, The Kardar-Parisi-Zhang equation - a statistical physics perspective, Les Houches Summer School July 2015 session CIV "Stochastic processes and random matrices", edited by Gregory Schehr, Alexander Altland, Yan V. Fyodorov, Neil O'Connell, and Leticia F. Cugliandolo, Oxford University Press, 2017.

A short review is:
- J. Quastel and H. Spohn, The one-dimensional KPZ equation and its universality class, Journal of Statistical Physics 160, 965--984 (2015).
KPZ and line ensembles are discussed in my notes from the summer school "Fundamental Problems in Statistical Mechanics":
- H. Spohn, Exact solutions for KPZ-type growth processes, random matrices, and equilibrium shapes of crystals, Physica A 369, 71 — 99 (2006).

Other events

Monday 5 February 2018, 2.30 pm
Gong Seminar‡

Monday 5 February 2018, 5.30 pm
Welcome drink

Wednesday 7 February 2018, 2.30 pm
Screening of the movie:
"Galois: Story of a Revolutionary Mathematician"
Director: Giuseppe Mussardo

Monday 12 February 2018, 5.30 pm
Wine & Cheese

Tuesday 13 February 2018, 2.30 pm
Seminar:
“The Riemann Conjecture”
by Giuseppe Mussardo

Thursday 15 February 2018, 2.30 pm
GGI inauguration§

‡ Each student is invited to give a two minute talk to present himself and his scientific interests.
§ The upgrading of GGI to “INFN National Center for Advanced Studies" is celebrated. The event is in Italian; it is not part of the School. See http://www.ggi.infn.it/showevent.pl?id=292 for details.