SFT-2015

Lectures on Statistical Field Theories
Galileo Galilei Institute
Florence, 2-13 February 2014

Program of lectures

Michel Bauer
A basic introduction to Markovian open quantum systems (6h)

Closed systems (classical or quantum) are always an idealization of reality. In order of increasing complexity first come the Markovian open systems for which interactions with the environment are taken into account but their effect depends only on the immediate past of the system's density matrix.
In these lectures we motivate the relevance and consistence of the Markovian approximation for open quantum systems. We also show a very deep connection between effects of an environment and effects of repeated indirect measurements.
We introduce non-demolition measurements and draw some broad conclusions on measurement in quantum mechanics. Next, we use non-demolition measurements as a tool to scrutinize the evolution of open quantum systems and analyze some properties of quantum trajectories.
Our focus is on properties that are related to classical probability theory. If time permits, we shall also touch briefly purely quantum aspects. We use the discrete time case to introduce the basic concepts, but also make the connection with continuous time systems.

Erez Berg
A new paradigms for non-Abelian statistics (6h)

Systems supporting non-Abelian statistics are promising platforms for future quantum information processing applications. Finding physical realizations of such systems is at the forefront of condensed matter physics.
In these lectures, I will describe a novel route to achieve this goal. I will explain how defects in Abelian topological phases can support protected zero modes with non-Abelian properties. In the presence of such defects, the ground state is multiply degenerate. One can define a `braiding' operation of defects, that can be thought of as a closed path in Hamiltonian space. This operation implements a unitary transformation on the low-energy manifold; remarkably, its result depends only on the topology of this path, rather than its exact shape. In this respect, the non-Abelian defects are analogous to `intrinsic' anyonic quasiparticles.
The mathematical framework that describes such defects is different from that of intrinsic anyons, however. I will discuss several physical examples of this phenomenon, including Majorana zero modes at the ends of topological superconductors, defects on the edges of quantum spin liquids, and fractional quantum Hall states. The latter realize `fractionalized Majorana' (or `parafermion') zero modes. Defects in a non-Abelian phase can enrich the properties of the underlying topological phase, rendering it universal for quantum computation.

Gesualdo Delfino
Exact S-matrices and applications (10h)

The aim of these lectures is to illustrate the use of the particle formalism for the exact determination of universal properties in two-dimensional statistical mechanics. The applications that will be discussed include magnetism, percolation, phase separation, interfaces, wetting.

Nicolas Regnault
Entanglement spectroscopy and its application to topological phases (6h)

The entanglement spectroscopy, initially introduced by Li and Haldane in the context of the fractional quantum Hall effects, has stimulated an extensive range of studies. The entanglement spectrum is the spectrum of the reduced density matrix, when we partition the system into two. For many quantum systems, it unveils a unique feature: Computed from the bulk ground state wave function, the entanglement spectrum give access to the physics of edge excitations. Using this property, the entanglement spectroscopy has proved to be a highly valuable tool to diagnose topological ordering.
These lectures intend to provide an overview of the entanglement spectroscopy. We introduce the basic concepts through the case of the quantum spin chains. We discuss the connection with the entanglement entropy and the matrix product state representation. We show how the entanglement spectrum can be computed for non-interacting topological phases and how it reveals the edge excitation from the ground state. We then present an extensive review of the entanglement spectra applied to the fractional quantum Hall phases, showing how much information is encoded within the ground state and how different partitions probe different type of excitations.

Kareljan Schoutens
Topological phases and CFT (10h)

Conformal field theories (CFT) describe the universal long-distance, low-energy behavior of critical systems in D=2 or D=1+1. At the same time they have important applications in organizing the description of specific topological phases formed by matter in a D=2 Landau level, the most spectacular examples being the so-called non-Abelian fractional quantum Hall (fqH) states.
We start the lectures by introducing the notion of topological (Chern) insulators and introducing Haldane's honeycomb model and the integer quantum Hall (iqH) system as basic examples.
After that we introduce CFT, highlighting its general structure and some applications to critical systems. We zoom in on CFTs that are prime players in the CFT-qH correspondence: WZW models and (generalized) parafermions.
We then explain the CFT-qH correspondence and show how it allows us to analyze the non-Abelian statistics of quasi-particles in specific qH systems. We will discuss Ising anyons in the Moore-Read state as well as Fibonacci anyons in more intricate fqH states.

Hour-by-hour plan:

1. Chern insulators and Haldane model
2. LLL and iqHe
3. CFT I - basic structure
4. CFT II – algebraic structure & null states
5. CFT III – minimal models & applications to critical systems
6. CFT IV – WZW models and parafermions

7. CFT V – fusion and braiding
8. CFT – qH correspondence
9. fqH – bulk & edge
10. Ising and Fibonacci anyons in qH systems.

Seminars

Denis Bernard
Non-Equilibrium Conformal Field Theory (2h)

We shall discuss how to describe some aspects of out-of-equilibrium phenomena in one dimensional quantum critical systems using tools from conformal field theories.

Martin Greiter
Introduction to Topological Insulators (2h)

Topological Insulators are two- or three-dimensional materials, which are insulating in the bulk, but possess topologically protected, gapless excitations on the surfaces. I will give an introduction to physical origin of this behavior, elaborate on the significance of time-reversal symmetry, and sketch the effective field theory of the surface states.

Giuseppe Mussardo
The Great Game. (1h)

An excursus across themes and history of group theory.