CONDENSED MATTER MANY-BODY-PHYSICS & FIELD THEORY I

TMP-TA3

LMU SoSe 2022

Prof. F. Grusdt

ORGANIZATION:

This is the second course taught in the series

- THP-TA1: Theor. Cond. Mat. Phys.
- THP-TA3: Cond. Mat. Many-Body-Phys. & Field Thy. I
- THP-TA4: Cond. Mat. Many-Body-Phys. & Field Thy. II

I will assume the following topics are known from previous theoretical physics courses:

* basics of classical mechanics
* basics of electromagnetism
* basics of quantum mechanics
* basic (quantum) theory of solids (band-theory, point-group symmetries, phonons, basic transport theory, ...)
* basics of statistical physics

Basic organization:

- We will have 2 lectures / week:

  WED $14^{\underline{15}} - 15^{\underline{45}}$

  FR $12^{\underline{15}} - 13^{\underline{45}}$

- We will have problem sets: 1 sheet / week

  ⇒ no grading, but solutions; first set on FR, Apr. 29

- We will have tutorials held by Felix Palm, Henning Schlömer

  ⇒ First tutorial on: TUE, May 03 (1st solutions on May 10)

- We will have a final exam on: ~ early Aug - TBC

- The lecture is worth 9 ECTS

0) CONTENTS:

Goal: The goal of this lecture is to learn the basic tools for describing quantum many-body systems. Such systems involve so many degrees of freedom that exact descriptions are almost always entirely impossible. Hence there are two main goals we can hope to achieve:

i) Develop a precise mathematical formalism to define well-posed physical/mathematical problems. I.e. learn to see your enemy!

=> This will be done at different levels of detail and mathematical rigor!

ii) Develop tools to actually solve a problem. Typically this requires studying very special models, or strong (and often poorly controlled) mathematical simplifications.

Ultimately, we only understand a rather limited set of physical problems, but many situations can be related to a known limit.

$\Rightarrow$ This leads to the idea of <u>universality</u> in (quantum or classical) many-body physics – namely that, independent of certain details that we need to specify, a characteristic type of collective behavior is observed.

Outline of the lecture:

1) Introduction

Many-body quantum systems, condensed matter, quantum simulation, emergent phenomena, open problems in the field

2) Second quantization & applications

Formalism, Weakly interacting bosons & Bogoliubov theory, Hubbard models: Mott insulators & Superfluids, 1D systems: Jordan-Wigner transformation, BCS theory of superconductivity: Mean-field theory

3) Green's functions & functional integrals

Green's functions & path integral representation

Coherent states & Grassman variables

Quantum-classical mapping

4) Landau Fermi-liquid theory

Weak interactions: Fermi liquid

Random phase approximation (RPA) & response functions (part 1)

Collective excitations

5) Quantum Magnetism

Fermi-Hubbard model: phenomenology

Heisenberg model: mean-field & spin-wave theory

1D Heisenberg chain: a quantum spin liquid

Field theory: non-linear σ-model

6) Feynman's diagrammatic perturbation theory

Formalisum & basic derivation: $T=0$

Examples: Lindhard function & Hartree-Fock energy

Screened Coulomb interactions: RPA and large N

Finite temperature formalism

7) Linear response theory

Formalism & application to Kubo formula

Fluctuation-dissipation theorem

Spectroscopic probes

8) BCS theory & charged superfluids

Hubbard stratonovich transformation: Derivation of Ginzburg-Landau theory

Anderson-Higgs mechanism

Literature:

- P. Coleman: "Introduction to Many-Body Physics"
- E. Fradkin: "Field Theories of Condensed Matter Physics"
- A. Auerbach: "Interacting Electrons & Quantum Magnetism"
- S. Sachdev: "Quantum Phase Transitions"
- X.-G. Wen: "Quantum Field Theory of Many-Body Systems"
- A. Altland, B. Simons: "Condensed Matter Field Theory"
- E. Fradkin: "Quantum Field Theory"

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