Applications of Quantum Field Theory (E16)

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This course will explore quantum field theories that emerge as the long distance, continuum, description of quantum many-body systems. These quantum field theories share important conceptual tools with those encountered in particle physics, such as renormalisation group flow, spontaneous symmetry breaking and diagrammatic perturbation theory. However, due to the immense diversity of many-body systems, which can have 1, 2 or 3 spatial dimensions, are not Lorentz invariant, and admit a variety of different collective modes, the quantum field theories to be considered in this course exhibit a range of rich and novel behaviours. Furthermore, while collider physics occurs in the vacuum, many-body physics takes place in states with a large number of particles and often at nonzero temperature. It becomes crucial to understand the interplay between quantum and thermal fluctuations.

Some subset of the following topics will be covered, as time allows:

- Spontaneous symmetry breaking in quantum many-body physics. Effective field theories of superfluids and magnets. Nonlinear sigma models. Coherent state path integral. Spin chains, topological terms and large S expansion.
- Nonzero temperature. Periodicity in imaginary time. Matsubara frequencies. Spectral functions. Fluctuation-dissipation theorem.
- Quantum Criticality. Quantum and themal fluctuations. Large N expansion.
- Effective field theory of Fermi surfaces. Renormalisation group picture of Fermi liquids. Superconducting instability of Fermi surfaces. Non-Fermi liquids.
- Dimerized and valence-bond solid phases. Spin liquids, spinons and emergent gauge fields. Deconfined quantum criticality and monopoles.

Prerequisites

Understanding of quantum field theory at the level of the Advanced Quantum Field Theory course is required. In particular, familiarity with path integrals and Wilsonian renormalisation will be assumed. Exposure to material in the Statistical Field Theory course (in particular, classical Landau-Ginzburg theory) and The Standard Model course (in particular, spontaneous symmetry breaking in quantum field theory) may be useful but will not be assumed. No prior exposure to solid state physics will be assumed.

Literature

1. S. Sachdev, *Quantum Phase Transitions*, 2nd Edition, CUP 2011.
2. X-G. Wen, *Quantum Field Theory of Many-Body Systems*, OUP 2004.
3. A. Zee, *Quantum Field Theory in a Nutshell*, PUP, 2003.
4. A. Altland and B. Simons, *Condensed Matter Field Theory*, 2nd Edition, CUP 2010.
5. S. Sachdev, *Quantum Phases of Matter*, CUP 2023.

Additional support

Two examples sheets will be provided and associated examples classes will be given. There will be a revision session before the exam.