Phys529 Topics of Quantum Theory: Quantum Fractionalization Phenomena in Non-Fermi liquids and CFT liquids

(Version: Nov 19, 2021, subject to further updates)

*Comment: Phys529 is intended for second year MSc students or first year PhD students who have completed basic trainings in theoretical physics. Students who have taken 1) QFT1 (**Phys526**) or QFT2 (**Phys508**) , 2) Statistical Mechanics (Phys**516**) or one of CMP graduate courses are welcome to attend the course.*

Part 0: Fermi Liquids—Prelude

1) Quasi-particles and the effect of renormalization

2) Zero sounds and various instabilities

3) Luttinger theorem on Fermi liquids

4) Basics of thermodynamics and dynamics

Part I: Non-Fermi liquids

1) The fate of quasi-particles

2) Examples of non-Fermi liquids:

2a) (Exactly) solvable Hatsugai-Kohmoto model

2b) A fermionic Nematic model

3) Connections to spin liquids and other fractionalization phenomena

4) Renormalization-group-equation approach to Non-fermi liquids:
Large-N, epsilon-expansion techniques

Part II: CFT liquids in (1+1)D as Non-Fermi liquids

1) 1D (complex) fermions with a "Fermi surface" and interactions

2) 1D Chiral anomaly of Dirac fermions

3) Schwinger terms and U(1) Kac-Moody Current Algebra

4) Bosonization and Fractionalization

5) Spinless CFT liquids and quasi-particle fractionalization

6) Spinful CFT liquids and spin-charge separation

Part III: CFT liquids in high dimensions: **(2+1)D, (3+1)D**

1) Basic results on CFT liquids in high dimensions

2) Anomalous dimensions of field operators and OPE in QFT

3) Relations to (Georgi's paradigm) un-particles in QFT

4) Case Studies via applications of QFT/CFT

4a) Emergent CFT liquids in a (2+1)D Bose-Hubbard Model

4b) CFT liquids in a (3+1)D Fermion-Hubbard model with z=2 and SO(2,1) symmetry

4c) CFT liquids in (2+1)D fermions and Fractionalization phenomena

Part IV: A New Paradigm of Quantum Dynamics/Quantum Metals: The Planckian limit

1) Conjectured quantum low bounds on particle interaction time

2) Quantum low bounds on quantum transport dynamics

3) Quantum low bounds on quantum hydrodynamics and the issue of entropy

4) Planckian dynamics via Large-N expansions, epsilon expansions

5) Connections to SUSY Holographic Matter in Ads/CFT and black hole dynamics.

General References:

General pedagogical discussions can be found in

1) Statistical Physics (Part II), Course of Theoretical Physics Vol9, Landau and Lifshitz (BH, Elsevier, 2003).

2) Field Theories in Condensed Matter Physics, E. Fradkin (Cambridge University Press, 2013)

3) Quantum Phase transitions, Subir Sachdev (Cambridge University Press, 2001).

General discussions on QFT calculations relevant to the course, see

4) Methods of Quantum Field Theory in Statistical Physics, Abrikosov, Gorkov, Dzyaloshinski (Dover, 1963).

5) Quantum Field theory: An introduction, Peskin and Schroeders (Westview, 1995).

General discussions on holographic matter, see the review article

6) Holographic Matter, Hartnoll, Lucas and Sachdev, https://arxiv.org/abs/1612.07324.

Marking Scheme (tentative):

1) There will be two homework sets (40%)

2) Each student will give three presentations on topics related Part I-IV (60%). Lists of selected topics will be provided as the term progresses and details will follow.