

Physics 561  
Fall Semester 2009  
Academic Year 2009/2010  
List of Suggested Term Papers

Professor Eduardo Fradkin

September 14, 2009

1. The Localization Transition.  
Reference: P. W. Andreson, E. Abrahams, D. C. Licciardello and T. V. Ramakrishnan (The Gang of Four), *Phys. Rev. Lett.* **42**, 673 (1979); F. Wegner, *Phys. Rev.* **B19**, 783 (1979) ; A. McKane and M. Stone, *Ann. Phys.* **131**, 36 (1981); S. Hikami, *Phys. Rev.* **24** , 2671 (1981).
2. Localization and Interactions. References: B.L. Altshuler, A.G. Aronov, D.E. Khmel'nitskii and A. Iarkin, in *Quantum Theory of Solids*, edited by I.M. Lifshitz (Mir Publishers, Moscow, 1982); C. Chamon, A.W.W. Ludwig, and C. Nayak, *Phys. Rev. B* **60**, 2239 (1999), cond-mat/9810282 .
3. Models of Polyacetylene.  
Reference: R. Jackiw and J. R. Schrieffer, *Nucl. Phys.* **B190** [FS3], 253 (1981); W. P. Su, J. R. Schrieffer and A. J. Heeger, *Phys. Rev.* **B22**, 2099 (1980); H. Takayama, Y. Lin-Liu and K. Maki, *Phys. Rev.* **B21**, 2388 (1980); D. K. Campbell and A. R. Bishop, *Phys. Rev.* **B24**, 4859 (1981); E. Fradkin and J. E. Hirsch, *Phys. Rev.* **B27**, 1680 (1983).
4. Quantum spin chains.  
Reference: F. D. M. Haldane, *Phys. Lett.* **A93**, 464 (1983); *Phys. Rev. Lett.* **50**,

- 1153 (1983); I.K. Affleck, *Phys. Rev. Lett.* **54**, 966 (1985); I.K. Affleck in *Strings, Fields and Critical Phenomena*, Les Houches Summer school 1988, Session XLIX, edited by E. Brezin and J. Zinn-Justin, North-Holland (1990).
5. Macroscopic Quantum Coherence: the Caldeira-Leggett model.  
Reference: A. Caldeira and A. J. Leggett, *Physica* **A121**, 587 (1983); *Ann. Phys. (NY)* **149**, 374 (1983) ; A. J. Leggett, S. Chakravarty, M. P. A. Fisher, A. Dorsey and W. Zwerger, *Rev. Mod. Phys.* **59**, 1 (1987).
  6. Field Theory approaches to the Quantum Hall Effect.  
Reference: S. C. Zhang, T. Hansson and S. Kivelson, *Phys. Rev. Lett.* **62**, 82 (1989) ; A. Lopez and E. Fradkin, *Phys. Rev.* **B44**, 5246 (1991); S. C. Zhang, *Int. J. Mod. Phys.* **62**, 25 (1992).
  7. Renormalization Group approach to Fermi Liquids.  
Reference: R. Shankar, *Rev. Mod. Phys.* **66**, 129 (1994); J. Polchinski, 1992 TASI Lectures *Effective Field Theory and the Fermi Surface* , arXiv:hep-th/9210046.
  8. Theory of the Kondo Problem.  
Reference: P. W. Anderson, *J. Phys.* **C3**, 2436 (1970); P. W. Anderson, G. Yuval and D. R. Hamann, *Phys. Rev.* **B1**, 4464 (1970); N. Read and D. Newns, *J. Phys.* **C16**, 3273 (1983); I. Affleck and A. W. W. Ludwig, *Nucl. Phys.* **B352**, 849 (1991).
  9. Bosonization of Fermi Liquids and Coherent States  
Reference: A. H. Castro Neto and Eduardo Fradkin, *Phys. Rev.* **B49**, 10877 (1994); *Phys. Rev.* **B51**, 4084 (1995); A. Houghton and J. B. Marston, *Phys. Rev.* **B48**, 7790 (1993).
  10. Quantum Dimer Models. References: D. Rokhsar and S.A. Kivelson, *Phys. Rev. Lett.* **61**, 2376 (1988); E.Fradkin, *Field Theories of Condensed Matter Systems*, Chapter 6; N. Read and S. Sachdev, *Nucl. Phys.* **B 316**, 609 (1989); R. Moessner and S. L. Sondhi, *Resonating valence bond liquid physics on the triangular lattice*, arXiv:cond-mat/0205029.

11. Gauge Theories and High  $T_c$  Systems. References: I. Affleck and J.B. Marston, Phys. Rev. B **37**, 3774 (1988); G. Baskaran and P.W. Anderson, Phys. Rev. B **37**, 580 (1988); Patrick A. Lee, Naoto Nagaosa and Xiao-Gang Wen, cond-mat/0410445.
12. Theory of Quantum Critical Behavior. References: J.A. Hertz, Phys. Rev. B **14**, 1165 (1976); A.J. Millis, Phys. Rev. B **48**, 7183 (1993); S. Sachdev, *Quantum Phase Transitions*, Cambridge University Press (1999).
13. Quantum impurities in Fermi Liquids. References: V. J. Emery and S. A. Kivelson, "Dynamical Impurity Problems", in *Fundamental Problems in Statistical Mechanics VIII*, Proceedings of the Altenberg Summer School, ed. by H. van Beijeren and M. H. Ernst (Elsevier, Amsterdam, 1993) pgs. 1-26; I.K. Affleck, *Conformal Field Theory Approach to Quantum Impurity Problems*, cond-mat/9311054.
14. Quantum impurities in D-wave superconductors. References: David Withoff and Eduardo Fradkin, *Phase transitions in Gapless Fermi Systems with Magnetic Impurities*, Phys. Rev. Lett. **64**, 1835 (1990); Lars Fritz and Matthias Vojta, cond-mat/0408543; A. Polkovnikov, S. Sachdev, and M. Vojta Phys. Rev. Lett. **86**, 296-299 (2001)
15. BCS theory of anisotropic superconductors and superfluids. References: D. Vollhardt and P. Wolfle, *The Superfluid Phases of He<sub>3</sub>*, Taylor & Francis (1990).
16. Stripes and high  $T_c$  superconductivity. References: E. W. Carlson, V. J. Emery, S. A. Kivelson, D. Orgad Comments: Review chapter to appear in 'The Physics of Conventional and Unconventional Superconductors' ed. by K. H. Bennemann and J. B. Ketterson (Springer-Verlag); E. Fradkin and S. A. Kivelson, *How optimal inhomogeneity produces high temperature superconductivity*, arXiv:cond-mat/0507459.
17. Carbon Nanotubes. References: *Correlation effects in carbon nanotubes* L. Balents and M.P.A. Fisher, Physical Review B **55**, R11973-6 (1997); L. Balents, *Orthogonality Catastrophes in Carbon Nanotubes*, 1999 Moriond Les Arcs Conference Proceedings, cond-mat/9906032.

18. Luttinger Liquids in one dimension. References: V.J. Emery, in *Highly Conducting One-Dimensional Solids*, edited by J.T. DeVreese, R.P. Evrard and V.E. van Doren, Plenum Press (1979); H.J. Schultz, G. Cuniberti and P. Pieri, *Fermi liquids and Luttinger liquids*, Lecture notes of the Chia Laguna (Italy) summer school, september 1997, 62 pages , published in “Field Theories for Low-Dimensional Condensed Matter Systems”, G. Morandi et al. Eds. Springer (2000), cond-mat/9807366; D. Senéchal, *An introduction to bosonization*, cond-mat/9908262; Reference: D. C. Mattis and E. Lieb, *J. Math. Phys.* **6**, 304 (1965); S. Coleman, *Phys. Rev.* **D11**, 2088 (1975); S. Mandelstam, *Phys. Rev.* **D11**, 3026 (1975); F. D. M. Haldane, *J. Phys. C* **14**, 2585 (1981).
19. Quantum Hall Effect on a Lattice.  
References: D.J.Thouless, M.Kohmoto, M.Nightingale and M.den Nijs, *Phys.Rev.Lett.* 46, 405 (1982).
20. Laughlin’s theory of the FQHE.  
References: R. Laughlin,*Phys.Rev.Lett.* 50, 1395 (1983). R. Laughlin’s article in Chapter 7 of the book by S.Girvin and R.Prange, *The Quantum Hall Effect*.
21. The single mode approximation to the collective modes in the FQHE.  
References: S. Girvin, A. MacDonald and P. Platzman, *Phys.Rev.Lett.* 54, 581 (1985); *Phys.Rev.B* 33, 2481 (1986). S. Girvin’s article in Chapter 9 of the book by S.Girvin and R.Prange, *The Quantum Hall Effect*.
22. Composite Fermions and Jain’s hierarchy. References: Jain J K. ,*Phys. Rev. B* 40, 8079 ( 1989); *Ad. Phys.* 41, 105 (1992)
23. FQH Compressible States and Fermi Liquids. References: B. I. Halperin, P. A. Lee and N. Read, *Phys. Rev.* **B47**, 7312 (1993). S.Simons and B. I. Halperin, *Phys. Rev. B* **48**, 17386 (1993), **50**, 1807 (1994).
24. Fractional Statistics. References: J. M. Leinaas and J. Myrheim, *II Nuovo Cimento* **37**, 1 (1977). F. Wilczek, *Phys. Rev. Lett.* **48**, 1144 (1982). D.Arovas, J.R.Schrieffer and F. Wilczek, *Phys. Rev. Lett.* 53, 722 (1984).

25. FQH Edge States and Chiral Luttinger Liquids. References: B.I.Halperin, Phys.Rev.B25, 2185 (1982). Xiao-Gang Wen, *Phys. Rev.* **B41**, 12838 (1990). Xiao Gang Wen, *Adv. Phys. (UK)*. 44, 405-73 (1995); Xiao Gang Wen, *Int. J. Mod. Phys. B6*, 1711-62 (1992). M.Stone, *Phys. Rev.* **B42**, 8399 (1990); *Ann.Phys.(NY)*206, 38 (1991); *Int. J. Mod. Phys. B5*, 509 (1991).
26. Duality in the FQHE. References: M. P. A. Fisher and D. H. Lee, *Phys. Rev.* **B39**, 2756 (1989) D. H. Lee and M. P. A. Fisher, *Phys. Rev.* **B46**, 2290 (1992). Dung Hai Lee and M P A. Fisher, *Phys. Rev.* B39, 2756-9 (1989); *Int. J. Mod. Phys. B5*, 2675-99 (1991); E.Fradkin and S.Kivelson, *Nucl.Phys.B474[FS]*, 543 (1996).
27. Tunneling into a FQH state. References: X.G.Wen, *Phys. Rev.* B44, 5708 (1991) C.Kane and M.P.A.Fisher, *Phys. Rev. Lett.* 68, 1220 (1992); *Phys. Rev.* B46, 15233 (1992); *Phys. Rev. Lett.* 72, 724 (1994). P. Fendley, A.Ludwig and H.Saleur, *Phys. Rev.* B52, 8934 (1995). C. de C. Chamon, D.Freed and X.G.Wen, *Phys. Rev.* B51, 2363 (1995); *Phys. Rev.* B53, 403 (1996).
28. Liquid Crystal Phases in Strongly Correlated Systems. References: S. A. Kivelson, E. Fradkin and V. J. Emery, *Electronic Liquid Crystal Phases of a Doped Mott Insulator* , *Nature* 393, 550 (1998); E. Fradkin and S. A. Kivelson, *Liquid Crystal Phases of Quantum Hall Systems*, *Phys. Rev.* B 59, 8065 (1999); Victor J. Emery, Eduardo Fradkin, Steven A. Kivelson, Tom C. Lubensky, *Quantum Theory of the Smectic Metal State in Stripe Phases*, *Phys. Rev. Lett.* **85**, 2160 (2000); Vadim Oganesyan, Steven Kivelson, Eduardo Fradkin, *Quantum Theory of a Nematic Fermi Fluid*, *Phys. Rev. B* 64, 195109 (2001); Erez Berg, Eduardo Fradkin, Steven A. Kivelson, John Tranquada, *Striped superconductors: How the cuprates intertwine spin, charge and superconducting orders*, arXiv:0901.4826.
29. Topological Insulators. References: C.L. Kane, E.J. Mele, *Z<sub>2</sub> Topological Order and the Quantum Spin Hall Effect* , *Phys. Rev. Lett.* 95, 146802 (2005) ; Liang Fu, C.L. Kane, E.J. Mele, *Topological Insulators in Three Dimensions*, *Phys. Rev. Lett.* 98, 106803 (2007) ; J. E. Moore, L. Balents, *Topological invariants of time-reversal-invariant band structures* , *Phys. Rev. B* 75, 121306(R) (2007) ; B. Andrei

- Bernevig, Shou-Cheng Zhang, *Quantum Spin Hall Effect*, Phys. Rev. Lett. 96, 106802 (2006); B. Andrei Bernevig, Taylor L. Hughes, Shou-Cheng Zhang, *Quantum Spin Hall Effect and Topological Phase Transition in HgTe Quantum Wells*, Science, 314, 1757 (2006); Xiao-Liang Qi, Taylor L. Hughes, Srinivas Raghu, Shou-Cheng Zhang, *Topological Superconductivity and Superfluidity*, Phys. Rev. Lett. 102, 187001 (2009); R. Roy, *Topological invariants of time reversal invariant superconductors*, arXiv:cond-mat/0608064; Alexei Kitaev, *Periodic table for topological insulators and superconductors*, arXiv:0901.2686.
30. Topological Quantum Computation and the Fractional Quantum Hall Effect. References: Chetan Nayak, Steven H. Simon, Ady Stern, Michael Freedman, Sankar Das Sarma, *Non-Abelian Anyons and Topological Quantum Computation*, Rev. Mod. Phys. 80, 1083 (2008); Sankar Das Sarma, Michael Freedman, Chetan Nayak, *Topologically-Protected Qubits from a Possible Non-Abelian Fractional Quantum Hall State*, Phys. Rev. Lett. 94, 166802 (2005); Alexei Kitaev, Chris Laumann, *Topological phases and quantum computation*, arXiv:0904.2771; A. Yu. Kitaev, *Fault-tolerant quantum computation by anyons*, arXiv:quant-ph/9707021.
31. Quantum Entanglement in Condensed Matter. References: Luigi Amico, Rosario Fazio, Andreas Osterloh, Vlatko Vedral, *Entanglement in Many-Body Systems*, Rev.Mod.Phys.80:517-576,2008; Gil Refael, Joel E. Moore, *Criticality and entanglement in random quantum systems*, arXiv:0908.1986; Ian Affleck, Nicolas Laflorencie, Erik S. Sorensen, *Entanglement entropy in quantum impurity systems and systems with boundaries*, arXiv:0906.1809; Pasquale Calabrese, John Cardy, *Entanglement entropy and conformal field theory*, arXiv:0905.4013; E. Fradkin *Scaling of Entanglement Entropy at 2D quantum Lifshitz fixed points and topological fluids*, arXiv:0906.1569.