

Physics 561
Fall Semester 2015
Academic Year 2015/2016
List of Suggested Term Papers

Professor Eduardo Fradkin

November 9, 2015

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. Khmelnitskii and A. Larkin, 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. Many-body localization.
D.M. Basko, I.L. Aleiner, and B.L. Altshuler, *Annals of Physics* **322**, 1126 (2006); R. Nandkishore and D. Huse, *Annual Reviews of Condensed Matter Physics* **6**, 15 (2015); V. Oganesyan and D. Huse, *Phys. Rev. B* **75**, 155111 (2007); C. R. Laumann, A. Pal and A. Scardicchio, *Phys. Rev. Lett.* **113**, 200405 (2014).
4. 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).
5. 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).
 6. 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).
 7. Field Theory approaches to the Quantum Hall Effect.
Reference: S. C. Zhang, T. Hansson and S. Kivelson, *Phys. Rev. Lett.* **62**, 82 (1989); A. López and E. Fradkin, *Phys. Rev.* **B44**, 5246 (1991); S. C. Zhang, *Int. J. Mod. Phys.* **62**, 25 (1992).
 8. 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.
 9. 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).
 10. 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).
 11. Quantum Dimer Models. References: D. Rokhsar and S.A. Kivelson, *Phys. Rev. Lett.* **61**, 2376 (1988); E. Fradkin, *Field Theories of*

- Condensed Matter Systems, Second Edition*, Chapters 8 and 9; N. Read and S. Sachdev, Nucl. Phys. B **316**, 609 (1989); R. Moessner and S. L. Sondhi, Progress of Theoretical Physics Supplement **145**, 37 (2002) (arXiv:cond-mat/0205029); R. Moessner, S. L. Sondhi and E. Fradkin, Phys. Rev. B **65**, 024504 (2001); E. Ardonne, P. Fendley and E. Fradkin, Annals of Physics **310**, 493 (2004).
12. 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.
 13. 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).
 14. 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.
 15. 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)
 16. BCS theory of anisotropic superconductors and superfluids. References: D. Vollhardt and P. Wolfe, *The Superfluid Phases of He₃*, Taylor & Francis (1990).
 17. 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;

18. 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.
19. 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).
20. Quantum Hall Effect on a Lattice.
References: D.J.Thouless, M.Kohmoto, M.Nightingale and M.den Nijs, *Phys. Rev. Lett.* **46**, 405 (1982).
21. 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*.
22. 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*.
23. Composite Fermions and Jain's hierarchy. References: Jain J K. ,*Phys. Rev. B* **40**, 8079 (1989); *Ad. Phys.* **41**, 105 (1992)
24. 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).

25. Fractional Statistics. References: J. M. Leinaas and J. Myrheim, *Il 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).
26. FQH Edge States and Chiral Luttinger Liquids. References: B.I.Halperin, *Phys.Rev.B***25**, 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).
27. 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. B***39**, 2756-9 (1989); *Int. J. Mod. Phys. B5*, 2675-99 (1991); E.Fradkin and S.Kivelson, *Nucl.Phys.B***474**[FS], 543 (1996).
28. Tunneling into a FQH state. References: X.G.Wen, *Phys. Rev. B***44**, 5708 (1991) C.Kane and M.P.A.Fisher, *Phys. Rev. Lett.* **68**, 1220 (1992); *Phys. Rev. B***46**, 15233 (1992); *Phys. Rev. Lett.* **72**, 724 (1994). P. Fendley, A.Ludwig and H.Saleur, *Phys. Rev. B***52**, 8934 (1995). C. de C. Chamon, D.Freed and X.G.Wen, *Phys. Rev. B***51**, 2363 (1995); *Phys. Rev. B***53**, 403 (1996).
29. 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*, *New Journal of Physics* **11**, 115004 (2009).
30. Topological Insulators. References: C.L. Kane, E.J. Mele, *Z₂ 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; S. Ryu, A. P. Schnyder, A. Furusaki, and A. W. W. Ludwig, New Journal of Physics, **12**, 065010 (2010).

31. 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.
32. 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.