Quantum field theory I – 253a
Tuesday+Thursday 2:37-4:07 Jefferson 256

- **Instructor**: Luboš Motl, motl at feynman.harvard.edu
- **TA**: Matthew Baumgart, baumgart at fas.harvard.edu
- **Pre-requisites**: More than introduction to quantum mechanics and classical electromagnetism
- **Section:** One hour per week: the details to be a subject of a vote
- **Official book**: Michael Peskin, Daniel Schroeder: An Introduction to Quantum Field Theory
- **Actual notes used in class**: Sidney Coleman's notes available at the my.harvard.edu course website (plus minus independent additions and subtractions and changes, especially when Sidney's material looks obsolete)
- **Grades**: 10 homeworks or so (60 percent) plus a final take-home exam (40 percent), unless changed, plus possible adjustment from constructive activity in the class
- **Homework**: Typically given on Thursday, due next Thursday
- **Exam Group**: 16,17
- **Catalog Number**: 8050
- **Summary of topics**: Introduction to relativistic quantum mechanics and quantum field theory. Canonical quantization, scalar and spinor fields, scattering theory, Feynman diagrams, renormalization

Additional sources – please feel to ignore the long list

- James Bjorken and Sidney Drell, Relativistic Quantum Mechanics and Relativistic Quantum Fields. This is an old favorite.
- John Cardy, Scaling and Renormalization in Statistical Physics. This book has quite a nice discussion of scaling and related phenomena, from the point of view of field theory.
- Sidney Coleman, Notes from 253a prepared by Brian Hill. These notes form an excellent basis for understanding field theory. A scanned copy of the (hand-written) notes will appear on the 253a web site. I will use a good deal of material from these notes.
- Sidney Coleman, Aspects of Symmetry, Selected Erice Lectures. This reprint volume has a nice introduction to symmetry breaking, etc.

- James Glimm and Arthur Jaffe, Quantum Physics, a Functional Integral Point of View. This book emphasizes conceptual principles and fundamentals of field theory, and in some later sections also has detailed calculations. It is the only text I know that explains the complete story relating path integrals (which are statistical physics) to quantum theory. Part I and some of Part III of this book are relevant to 253a.

- Brian Hatfield, Quantum Field Theory of Point Particles and Strings.

  This book is an elementary presentation of these two topics and their relation.

- Claude Itzykson and Jean-Bernard Zuber, Quantum Field Theory. For years this was a standard reference. It is useful and once was the course text.

- Franz Mandl and Graham Shaw, Quantum Field Theory. This is a revision of a very old favorite. It is written in a direct, less is more fashion, but does provide details about many things. It is a good starting point.

- Lewis Ryder, Quantum Field Theory. This book is popular with students, especially for the elementary portions.

- Mark Srednicki's textbook, online, http://www.physics.ucsb.edu/~mark/qft.html

- Raymond Streater and Arthur Wightman, PCT, Spin and Statistics, and All That. This is the standard reference on the (interacting) quantum field theories that follow from Poincar invariance, positive energy, and locality (for example, the spin and statistics theorem and the CPT theorem). Sometimes one refers to these three fundamental assumptions as the Wightman axioms.

- Steven Weinberg, Quantum Field Theory, vol 1-3. This interesting set of books covers both conceptual issues and detailed calculations. The notation tends to be complicated and the presentation complete but immersed in detail, so a beginning student may have trouble with this book. But it reaps many rewards and serves as an excellent reference.

- Anthony Zee, Quantum Field Theory in a Nutshell. This is a new book. It mentions many things without much detail.

Advanced material not covered in this course

Phenomenology, string theory, and M-theory:

- Michael Dine, Supersymmetry and String Theory: Beyond the Standard Model, December 2006. Almost everything you wanted to know about phenomenology, particle physics, including cosmology. Practically oriented.

- Michael Green, John Schwarz, and Edward Witten, Superstring Theory, Volumes 1-2. This is a basic, well-written text.

- Katrin Becker, Melanie Becker, John Schwarz, String Theory and M-Theory: a Modern Introduction, November 2006.

- Joseph Polchinski, String Theory, Volumes 1-2. Still mainstream modern textbook on string theory, especially with focus on conformal field theory.
- Barton Zwiebach, A First Course on String Theory. Based on an award-winning undergraduate course at MIT.

Schedule of lectures (approximate)

- Sep 19: units; action of translations, rotations, and Lorentz symmetry on one particle states
- Sep 21: position operator; violations of causality; pair-production; Fock space with harmonic oscillators and occupation numbers
- Sep 26: causality; axiomatic construction of quantum field theory and observables from Fock spaces; rotational and Lorentz invariance; relativistic normalization; verification of Klein-Gordon equation
- Sep 28: deriving Fock space from quantum fields; classical and quantum mechanics; classical and quantum field theory; free scalar QFT
- Oct 3: Hamiltonian in free scalar QFT; additive shifts and normal ordering; symmetries and conservation laws via Noether's theorem in field theory; ambiguities of conserved currents and stress-energy tensor
- Oct 5: Lorentz transformations, rotations; angular momentum and internal symmetries: SO(2), SO(n), charged fields
- Oct 10: Lorentz transformation properties of conserved quantities; discrete symmetries: charge conjugation, parity, time reversals; anti-unitary operators
- Oct 12: scattering theory overview; low budget scattering; turning on/off function; pictures: Schrödinger, Heisenberg, Dirac (interaction); evolution operator; time-ordered product; three models; Wick's theorem
- Oct 17: diagrammatic perturbation theory; connected diagrams and all diagrams as their exponential; solving models
- Oct 19: finishing solving models; vacuum energy and ground state energy; Yukawa potential; mass renormalization; renormalized perturbation theory
- Oct 24: Feynman rules in a model; a list of all Feynman diagrams up to a given order
- Oct 26: nucleon scattering
- Oct 31: kinematical factors for decay rates; cross sections; flux; phase space; two-body simplifications; optical theorem; off-shell diagrams – with external legs off the mass shell – can be inside more complex diagrams
- Nov 2: LSZ formula and various interpretations of off-shell Feynman diagrams

- Nov 7: proof of LSZ formula; renormalizing a particular model; renormalization conditions
- Nov 9: starting to evaluate perturbative corrections; renormalization conditions from 1PI actions and from Green's functions; problems with derivative couplings
- Nov 14: one-loop corrections: external lines; meson self-energy; Feynman's trick to reconcile different denominators; making the denominator SO(3,1) and, after Wick rotation, SO(4) invariant; tables of convergent integrals over Feynman parameters
- Nov 16: coupling constant renormalization from 1PI functions; infinities vs. renormalization; renormalizable Lagrangians and experimental significance of the differences
- Nov 21: unstable particles and decay products continued; lifetime; equivalent and inequivalent representations of SO(3); unitarity; complex conjugation; direct products; reducible representations and projection operators
- Nov 23: Lorentz group, algebra, and their representations; tensors; spinors
- Nov 28: Weyl, two-component spinor, and its Lagrangian; Dirac, four-component spinor, and its Lagrangian; plane wave solutions; Weyl and Dirac basis
- Nov 30: Dirac equation; Pauli's theorem; Dirac adjoint; Pauli-Feynman notation; parity; bilinears; orthogonality, completeness; summary
- Dec 4: canonical quantization of the Dirac Lagrangian
- Dec 6: perturbation theory for spinors; propagator (contraction); Wick diagrams; Feynman diagrams; spin averages and spin sums; matrix multiplication
- Dec 11: parity of fermions and the opposite parity of antifermions; Majorana basis; charge conjugation and its action on bilinears; decay of ortho/para positronium; PT reversal
- Dec 13: Effect of PT on states; perturbative proof of the CPT theorem; renormalization of theories with spinors
- last lectures: regularization and renormalization; its sufficiency or insufficiency to eliminate infinities; renormalization of composite operators and modern understanding of renormalization: renormalization group