Physics 716

Quantum Field Theory II (3 credits)

Spring 2012

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Office hours: Tuesday, 2:00-4:00 pm, or by appointment.

Class meets Tuesday, Thursday, 9:30-10:45 am (CP 397). There will be no classes on Tuesday, March 13 and Thursday, March 15 (Academic Holidays).

Grading: I will give you home assignments approximately every 10 days. Your homework will be graded (40 points). Solutions to all problems will be placed in the library. I advice you to read my solutions with great care. If you have any questions about my solutions (as I expect you would), you are welcome in my office for discussion. I encourage you to discuss the homework together, and even to work on it together. However, you should *write up your homework separately.* Identical solutions would not earn any points.

There will be no midterm exam. There will be a take-home final exam due Tuesday, May 4 (60 points). It could happen that I will change my mind and ask each of you to prepare a short talk (20-25 min) instead of the final exam.

Student Evaluations: Course evaluations are an important (and mandatory!) component of our Department's instructional program. The evaluation window for Spring 2012 will open on Monday, April 9, and close on Wednesday, April 25th. To access the system during this time, simply go to "Courses" on the A&S Departmental Website page, and click on the link for Course Evaluations; then follow the instructions. You will need to use your student ID# to log into the system, and this will also allow us to monitor who has filled out evaluations. However, when you log-in you will be assigned a random number that will keep all your comments and scores anonymous.

Textbook: M. E. Peskin and D. V. Schroeder, An Introduction to Quantum Field Theory, Addison-Wesley, 1995, ISBN 0-201-50397-2. You can find corrections to the printed version at
http://www.slac.stanford.edu/~mpeskin/QFT.html

Other useful books:

- Anthony Zee, Quantum Field Theory in a Nutshell, Princeton University Press, Princeton and Oxford, 2003, ISBN 0-691-01019-6. You can find corrections to the printed version at
  http:// theory.kitp.ucsb.edu/~zee/nuts.html
- J. D. Bjorken and S. D. Drell, Relativistic Quantum Mechanics and Relativistic Quantum Fields, 1966
- G. Sterman, An Introduction to Quantum Field Theory, 1993
- P. Ramond, Field Theory: A Modern Primer, 2nd edition, 1989
- S. Weinberg, The Quantum Theory of Fields, volumes I, II, Cambridge University Press, 1996
- Kerson Huang, Quantum Field Theory, John Wiley & Sons, 1998
- J. Zinn-Justin, Quantum Field Theory and Critical Phenomena, 3d edition, 1996
- M. Srednicki, Quantum Field Theory, Cambridge University Press, 2007

- V. B. Berestetskii, E. M. Lifshitz, and L. P. Pitaevski, Quantum Electrodynamics, Butterworth-Heinemann, 1982.
- T. Banks, Modern Quantum Field Theory, Cambridge University Press, 2008

The Syllabus

1. **Simplest QED Processes in the Born Approximation**
   - Electron-positron annihilation into hadrons, November revolution and quarks.
   - Crossing symmetry. Electron-muon scattering.
   - Compton effect.
2. **One-Loop Radiative Correction in QED**
   - Vertex, Self-Energy, and Polarization Insertions in the Scattering Amplitudes. Ultraviolet, Infrared and Physical Singularities of Scattering Amplitudes.
   - Classical and Quantum Soft Bremsstrahlung. On-Shell Vertex. Form factors and their Physical Interpretation. Renormalization Constant Z_1.
   - Integration over Loop Momentum, Structure of Singularities, Wick Rotation. Divergences, Regularization, and Subtractions. One-loop anomalous magnetic moment. One-Loop Vertex Correction with On-Mass-Shell Legs and the Infrared Divergence.
   - Exact Two-Point Functions. Mass and Wave Function Renormalization. Self-energy operator. Renormalization Constant Z_2.
3. **LSZ reduction formulae, Ward Identities, Optical Theorem**
   - LSZ reduction formulae. Ward-Takahashi Identity and $Z_1 = Z_2$.
   - Optical Theorem. Cutkosky rules. Dispersion relations. Källen-Lehmann representation for the polarization operator.
   - Photon wave function renormalization constant Z_3. Charge Renormalization. Zero-charge problem in QED. Dimensional regularization. Polarization operator in dimensional regularization.
4. **Renormalization to All Orders**
   - Degree of Superficial Divergence. Finite, Superrenormalizable, Renormalizable, and Nonrenormalizable Theories
   - Total and Counterterm Lagrangians in QED. Renormalization Constants. Connection between Physical and Bare Charges in QED. Landau Pole. Running Coupling Constant, β-function in QED and ϕ^4 Theory. Classification of Different Types of Asymptotic Behavior. Asymptotic Freedom and Infrared Slavery. Fixed Points.
5. **Symmetry and Symmetry Breaking in the Tree Approximation**
   - Global Discrete and Continuous Symmetries in Classical Physics, Quantum Mechanics, and Quantum Field Theory
   - Wigner-Weyl Realization of Global Continuous Symmetry. Spontaneous Breaking of Global Continuous Symmetry. Impossibility to Break Global Continuous Symmetry in $d \leq 2$.

- Nambu-Goldstone Realization of Global Continuous Symmetry. Massless Goldstone Boson. Goldstone Theorem. Small Explicit Symmetry Breaking and Masses of Pseudo Goldstone Bosons. Spontaneous Chiral Symmetry Breaking in QCD, masses of Pseudoscalar Octet Particles, and Light Quark Mass Ratios
- Higgs Effect in $U(1)$ Gauge Theory

6. **Functional Integral Quantization**

- Path integral representation of the propagation function in QM. Functional Integral in QFT. Green Functions.
- Generating Functional and the Feynman Rules. Connection between QFT and Statistical Mechanics.
- Faddeev-Popov Trick and Quantization of the EM Field.
- Functional Integral for Fermions.
- Quantization of the Abelian Higgs Model. Faddeev-Popov Determinant and R_ξ Gauge. Fermion Mass Generation Mechanism. Example of ξ-Dependence Cancelation

7. **Nonabelian Gauge Theories**

- Nonabelian Gauge Theories. Quantum Chromodynamics
- Gauge Fixing in Nonabelian Theory. Faddeev-Popov Determinant and Ghosts. Feynman Rules for Nonabelian Gauge Theories
- Summary of Weak Interactions Phenomenology. Higgs Effect in $SU(2)$ Theory.
- Glashow-Weinberg-Salam Theory. Vector-Spinor Interaction in Electroweak Theory. Charged Currents
- Photon and Z-Boson Fields. Effective Neutral Current Interaction at Low Energy
- Vector-Scalar and Pure Gauge Interactions in EW Theory
- Fermion Masses in EW Theory