Quantum Field Theory I: Fall 2020

11 Thaw Hall M-W-F 3:00 pm → 3:50 pm

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SYLLABUS:

Basics of field quantization: from particles to fields, from fields to particles. Lagrangian and Hamiltonian dynamics: Euler-Lagrange equations, Poisson brackets. Field quantization: Elastic waves: phonons, the continuous string: a real scalar field. Quanta as particles. Relativistic QFT: brief review of special relativity. Lorentz transformation laws for fields. Causality. Symmetries and conservation laws: Noether's theorem, the energy momentum tensor, conserved currents and symmetry generators. Topological conservation laws: solitons. The relativistic real and complex Klein-Gordon (scalar) fields (Higgs field): global gauge symmetry. Microscopic causality and commutators. Green's functions: advanced, retarded and Feynman. Applications: i) linear response, ii) particle production by external sources, iii) effective field theory and interactions. Interlude: Second quantization of the Schroedinger field: non-relativistic many body physics. Quantized electromagnetic field: photons: (spin 1) gauge invariance, physical degrees of freedom, microscopic causality and propagators. The massive vector field (Proca) (W,Z gauge bosons) the propagator. Effective field theory: massive vector boson exchange: effective low energy field theory.

Dirac field: Dirac equation, non-relativistic limit, minimal coupling and correct gyromagnetic factor. Spin ½. Helicity. Quantization, Anti-commutators: the Pauli exclusion principle. Spin statistics connection. Weyl and Majorana fermions. Antiparticles. Propagators. Connection to CM: graphene and Weyl semimetals. Minimal coupling between electromagnetic and charged fields and gauge invariance. Gyromagnetic factor of the electron and Thomas factors.

Interacting fields discrete symmetries, parity, charge conjugation and time reversal, intrinsic parity. PCT theorem. P and C violation in weak interactions: the Co60 expt. S-matrix. Feynman diagrams/calculus: Wick's theorem. Cross sections and decay rates: examples. Unitarity. Disconnected (vacuum) diagrams Quantum electrodynamics: elementary processes: cross sections: Casimir ``trick''. Self-energy corrections, Dyson series and resummation: effective propagators. Examples. Resonances: Breit-Wigner propagators and resonant cross sections. Interpretation of the time evolution. Loops: scalar field theory, regularization: dimensional regularization. Renormalization in QED: Ward identities, dimensional regularization, g-2, Lamb shift effective running coupling: screening. Dressed electrons. Renormalized perturbation theory: counterterms. Dressing by virtual excitations, Gell-Mann-Low theorem. Quasiparticles.
Asymptotic states: in-out formulation of S-matrix elements. Correlation functions and their relations to cross sections. Structural aspects: spectral representations and dispersion relations.

Brief description of QFT II:

Non-abelian gauge theories: QCD, asymptotic freedom and confinement. Spontaneous symmetry breaking, Goldstone modes, Higgs Mechanism. Connections with condensed matter: Meissner effect in superconductivity. Symmetry breaking in the Standard Model, the Higgs mechanism and origin of masses.
Path integral quantization and connection to statistical mechanics. Gauge theories in the path integral formulation. LSZ formalism, from path integrals to cross sections. Renormalization group.

Useful books: I will draw material from many different books: QFT and the Standard Model, by M. Schwartz, QFT by Peskin/Schroeder, Relativistic QM and field theory: F. Gross, QFT by Mandl and Shaw, any of the more recent books will do. I will share my class notes (see below).

FORMAT OF THE CLASS: Classes begin Wednesday August 19th.

Anticipating a sustained period of online instruction, the class will be fully on-line for the Fall semester. Classes will be given via **Zoom**, I will send Zoom links to the class to all students 10 minutes before the class: 2:50 PM M-W-F. Each class will be recorded for later access and asynchronous learning. After each class the link to the Zoom Video recording will be sent to all enrolled students.

I will adopt the following format: two days prior to each class I will send a pdf with the class notes to all enrolled students. This will give students the opportunity to preview the material before the class. During the class I will go over this material focusing on the concepts, highlighting the most important technical aspects, answering questions and engaging in discussions. For the first class on August 19th, I will send the class notes in the afternoon of Monday August 17th.

After each class I will send all registered students a scanned copy (pdf) of my class notes for the **next class,** with references and any supplementary material, and the link to the Zoom Video recording of the class that just ended. In this manner each student will have unfettered access to the class material both prior, during, and after the class. This option also gives all students access to asynchronous learning.

Office hours: I am available on a flexible schedule, I will answer e-mail questions any time, and within the same day of receiving the question, if necessary we can set up an individual Zoom meeting to discuss at a time of mutual convenience.

There will be one homework a week (about 4-5 problems) due back the following week. The homework will be sent by e-mail (in pdf format) to all registered students right after a Friday class and is due back the next Friday after class by sending me an e-mail with a pdf (or alternative format compatible with Windows OS) with all the pages and clear work. Please label equations so I can refer to the particular equation when I revise the homework.

Although I value in-person teaching, I am convinced that while this format is not optimal, at least it provides a consistent, uninterrupted and continuous learning platform. I am committed to providing an enriching and worthwhile learning experience.