In 1930, Dirac developed relativistic Quantum Theory of the electron and predicted the existence of the anti-electron. Eventually, it was found that many particles had an anti-matter twin. Since particles could be created and destroyed, the old one-particle quantum theory of Schroedinger and Heisenberg that required $\int |\psi|^2dV=1$ was inadequate. So a new theory was developed, Quantum Field Theory (QFT) that describes the creation, annihilation and interactions of particles and anti-particles. The successful QFT model has been Quantum Electrodynamics, developed by Feynman, Schwinger, Tomonaga and Dyson in the 1940’s, and it describes fermions and photons interactions in terms of a renormalizable perturbation series (Feynman diagrams) to extraordinary precision. In addition, Feynman generalized these ideas into path integrals which treats quantum mechanics as summing all possible quantum amplitudes of particles going forward and backwards in time.

The Standard Model, invented by Glashow, Weinberg and Salam in 1967, unified the weak and the electro-magnetic interactions and explains the forces between leptons and quarks as the exchange of massless gauge vector particle fields (photon, gluon, W+, W- and Z°). Now, this has been verified by the discovery of the heavy gauge vector bosons, W and Z, in 1983 and very recently by the 2012 discovery of the Higgs boson which explains how the W and Z become massive. So the basic 1967 Standard Model of particles has been verified and today it is the analog of Maxwell’s equations that were written down about 100 years earlier in 1862.

Field theory has many important applications in condensed matter where the partition function of statistical physics is directly related to the Feynman path integral and quasi-particles in condensed matter actually follow the Dirac and Majorana equations of charged and neutral fermions. The next 50 years of this century will likely see some spectacular developments and applications from QFT which none of us can predict. It will be important for well-informed physicists to study at least the basics of Quantum Field Theory to understand important future physics and applications of this century.

In this course, the minimum Quantum Field theory will be developed and then the basic Standard model and statistical field theory will be covered. Depending on the interest and available time, various special topics may be covered in modest detail.

Course Description; We aim to cover the following material (lectures not necessarily in this order)
(1) Review of non-relativistic Schrodinger Quantum Mechanics, Dirac bracket notation, boson and fermion wave functions, and 1st quantization using commutators
(2) Fock space, creation and annihilation operators, commutators and anti-commutators, field operator quantization and many body theory. Field theory and 2nd quantization of Schrodinger Eqn
(3) Review of Special Relativity, transformation matrices, tensor notation, covariant and
tcontravariant tensors, and neutrino oscillations.
(4) relativistic one-particle theory, Klein-Gordon Eqn. (spin 0), plane wave solutions, and
quantization of the K-G field.
(5) relativistic one-particle theory, Dirac Eqn. (spin ½), hole theory, anti-particle solutions,
rotation and Lorentz transformation of the Dirac wave function.
(6) Green function solutions to Dirac Eqn. and Feynman diagrams
(7) 2nd quantization of electromagnetic field (boson field)
(8) 2nd quantization of Dirac field (fermion field)
(9) S-matrix expansions and the Interaction picture, time ordered perturbation expansion, normal
ordering, Feynman diagrams, first order QED diagram calculations.
(10) Statistical Physics, functionals, path integrals, field integrals, Statistical Field Theory
(11) Group theory, U(1), SU(2), SU(3) groups, quark model, and local and global gauge
invariance.
(12) Weak interaction of leptons, quarks, and gauge bosons. The Standard model, Weinberg-
Salam Model, SU(2)xU(1) gauge invariance, local gauge invariance, spontaneous symmetry
breaking, calculation of Higgs, W and Z decays and neutrino scattering.
(13) Special topics;
   a. PMNS-neutrino mixing matrix and neutrino mixing.
   b. CP violation in neutrinos, Majorana neutrinos, see-saw mechanism.
   c. Double beta decay, Parity violation in atomic physics
   d. Kobayashi-Maskawa matrix, weak decays of quarks, CP violation in Quarks.

Prerequisites; at least one semester of graduate Quantum Mechanics at the level of Sakurai’s
Modern QM text book (PH651/652) and some knowledge of special relativity. This course does
not require an advanced particle physics background.

The handwritten lecture notes (saved from the PC tablet) will be posted online for students to
refer to later and possibly print out. I will also pass out useful type written documents of
formulae for various topics. The course will have homework problem sets every two weeks and
no exams. Students will need to work out problems to really understand the material. I will
provide basic pedagogical problems that are useful for learning the material.

GRADING; based on bi-weekly homework problems. Most problems will be from the Lancaster
& Blundell textbook.

TEXTBOOK; Quantum Field Theory for the Gifted Amateur, by Tom Lancaster and Stephen
Blundell. (2014) ISBN 978-0-19-969933-9. This is the primary textbook for the course. We will
follow this new textbook working ~chapter per lecture. This book covers both condensed matter
and relativistic particles. We primarily concentrate on the particle (especially weaks decays for
neutrino physics) and condensed matter (statistical field theory and Dirac/Majorana particle)
applications.

REFERENCE TEXTBOOKS; these are highly recommended references.
1) Quarks and Leptons, by Halzen and Martin (1984), bible for Standard Model calculations.
2) Advanced Quantum Mechanics, by J. J. Sakurai (1967), classic textbook for Q.E.D., but uses old notation.
3) Advanced Quantum Mechanics, by Franz Schwabl, (2005), QC174.12 S38813. This is a standard Particle Field Theory textbook, and IT IS ONLINE IN THE CSU LIBRARY.

ROUGH Course Lecture Materials (three 50 minute lectures per week)

1) Week 1; L&B chapter 2 and 3, Harmonic Oscillators and Occupation number representation
2) Week 2; L&B chapter 4, 2nd Quantization, 1 lecture due to labor day holiday
3) Week 3; L&B chap 5-6, Lagrangians and Hamiltonians, Relativistic QM
4) Week 4; L&B chap 7-8, scalar theory, time dependent QM
5) Week 5; L&B chap 9-10, QM transformations, symmetry
6) Week 6; L&B chap 11-12, canonical quantization
7) Week 7; L&B chap 13-14, EM fields and Gauge theory
8) Week 8; L&B chap 15-16, discrete transformations, green functions
9) Week 9; L&B chap 17-20, propagators, fields, S-matrix, Feynman diagrams
10) Week 10; L&B chap 21-25, Statistical Physics, Path integrals, Statistical field theories.
11) Week 11; L&B chap 36-37, Dirac Eqn and Dirac spinors
12) Week 12; L&B chap 38-39, Dirac Fields and Q.E.D.
13) Week 13; L&B chap 40, Q.E.D. examples
14) Week 14; L&B chap 46, Standard Model
15) Week 15; L&B chap 47, Standard Model and Majorana neutrinos