Introduction to PHY 855

PHY 855 - Quantum Field Theory

“Introduction to field theory as it pertains to numerous problems in particle, nuclear and condensed matter physics. Second quantization, applications to different fields based on perturbation theory. Offered first half of semester.”

PHY 955 - Relativistic Quantum Field Theory

“Theory of relativistic quantum fields and renormalization with emphasis on applications for particle physics. Offered second half of semester.”

A short history of quantum field theory

- The first formula of quantum physics was $E = h\nu$, published by Planck in 1901.
  h = Planck's constant
  ν = frequency of an electromagnetic wave
  E = photon energy of the wave
- For Planck, eq. (1) was a *hypothesis* with no theoretical justification.
- The theoretical justification was provided by Dirac in 1930, in the theory of the quantized electromagnetic field.
- The theory was developed, through the use of *renormalization* , by Feynman and by Schwinger around 1949.
- Q.E.D. is the most accurate theory in physics : it has been tested to the limits of precision of experimental measurements.

Introduction to PHY 855 and 955

PHY 955 is on ***relativistic*** quantum field theory (RQFT), like Q.E.D.

PHY 855 is on ***nonrelativistic*** quantum field theory (NRQFT).

RQFT is more fundamental:

/1/ NRQFT is not consistent with special relativity.

/2/ NRQFT is an approximation to RQFT, valid if the relevant forms of energy (kinetic, potential, field energies) are $\ll mc^2$.

/3/ The fundamental interactions (except gravity) are described by RQFTs.

Introduction to PHY 855

If NRQFT is not fundamental, why do we study it?

NRQFT is the best ***practical*** theory for atomic physics, condensed matter physics and nuclear physics. It is not practical to try to use RQFT for these subjects.

(Concerning high-energy physics, NRQFT is useless. However, understanding the ideas of the simpler low-energy theory, helps when learning the more complicated RQFT.)

NRQFT might also be called quantum many-body theory.

It applies to the quantum description of systems with many degrees of freedom --- i.e., many “particles”:

- .atomic physics; energies range from eV to keV; $m_e c^2$ = 0.5 MeV
- .condensed matter physics; energies range from meV to eV.
- .some parts of nuclear physics ; e.g., energy level differences range from 0.1 MeV to 100 MeV; $m_N c^2$ = 940 MeV. (Some parts of nuclear physics, e.g., meson physics, or RHIC, or neutrino interactions do require RQFT.)

In the interest of "full disclosure" …

I am expert in relativistic quantum field theory, but not in NRQFT.

I have never taught PHY 855 before.

No one has ever taught PHY 855 before --- it is a new course in our new graduate curriculum. But there might be more qualified instructors for PHY 855. I am still learning the subject.

We'll use this book:

Fetter and Walecka, *Quantum Theory of Many-Particle Systems.* It's a rather old book (© 1971) but still widely used. This is the standard textbook for this subject in America.

Other books on NRQFT:

Abrikosov et al, *Green's function methods in statistical physics;* emphasis on applications in statistical mechanics and condensed matter physics.

Negele and Orland, *Quantum Many Particle Systems;* more recent, with an emphasis on the Feynman path integral.

Dickhoff and Van Ne, *Many Body Theory Exposed;* more recent, with some emphasis on comparison to more recent experiments.

There are many other books on this subject.

Syllabus

Chapter 1 - Second Quantization

Chapter 3 - Green's functions and field theory (fermions)

Chapter 4 - Fermi systems

Chapter 11 - Nuclear matter

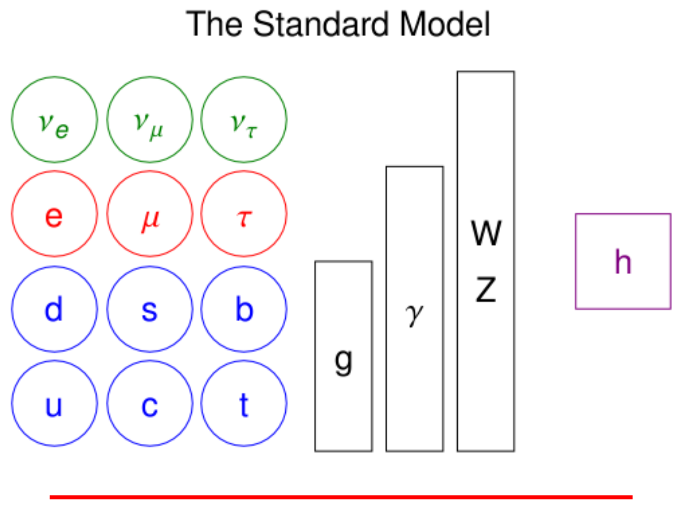
Chapter 12 - Phonons and electrons

Grading will be based on six homework assignments

We only have 7 weeks, so the emphasis of the course will be to understand the basic ideas.

Matter and Energy

The standard model of high-energy physics



Condensed matter physics: the electron

Traditional nuclear physics: protons and neutrons — approximated as elementary particles.

Q.F.T : we need to change some ways of thinking.

/1/ Old way of thinking: An electron is a particle, or maybe a wave.

New way of thinking: An electron is an excitation of the electron field.

/2/ Old way of thinking: A proton (or neutron) is a particle, or maybe a wave.

New way of thinking: A proton (or neutron) is an excitation of the proton (or neutron) field.

(Or, *new* new way of thinking: A nucleon is a bound state of quark and gluon fields.)

/3/ Old way of thinking: $\psi(\mathbf{r},t)$ is a wave function; or a probability amplitude.

New way of thinking: $\psi(\mathbf{r},t)$ is a quantized field; i.e., an operator on the Fock space of occupation numbers.

/4/ Old way of thinking: $\mathbf{r}$ and $\mathbf{p}$ are functional operators on a wave function; $\mathbf{p} = -i\hbar\,\boldsymbol{\nabla}$.

$\mathbf{r}$ only denotes a point in space; $\mathbf{p}$ only denotes a point in momentum space.

/5/ Old way of thinking:
energy = $\Sigma_i[\mathbf{p}_i^2/2m + V(\mathbf{r}_i)]$ + interaction energies

New way of thinking:
$H = \int \{ |\nabla\psi|^2\, \hbar^2/2m + V\,|\psi|^2 \}\, d^3r + \psi\psi V\psi\psi$,
(an operator on the Fock space).