Physics 431: Particle and Nuclear Physics   Spring, 2016

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Prerequisites: PHY 308 (quantum physics); it is also assumed that students have taken more elementary courses including PHY 251 (modern physics).

Course requirements: homework, midterm, and final exam

First meeting time/place: Tue. Jan. 26, 8:30 AM, Rm. P129; office hr. TBA

The main textbook is D. Griffiths, *Introduction to Elementary Particles* (2010). Two recommended books are C. Quigg, *Gauge Theories of the Strong, Electromagnetic, and Weak Interactions* (2013) and E. M. Henley and A. Garcia, *Subatomic Physics* (2007). We will also use information from various websites.

This is a senior-level undergraduate course on particle and nuclear physics covering topics chosen from the following list:

- Basic properties and interactions of elementary particles
- Early history of discoveries of elementary particles and connection with nuclear physics
- Relativistic kinematics, calculation of scattering cross sections and decay rates
- Dirac equation, gamma matrices
- Introduction to quantum field theory, Lagrangians, and use of Feynman diagrams for perturbative calculations
- Accelerators and particle detectors
- Symmetries, groups, and conservation laws; SU(2) and spin; chiral and vectorial "flavor" symmetries including $SU(N_f)_L \times SU(N_f)_R$ and $SU(N_f)_{vec}$ with $N_f = 2,\ 3$, and their dynamical basis
- Concept of gauge invariance, gauge interactions; abelian (QED) and non-abelian (Yang-Mills)
- Electromagnetic interactions and properties of elementary particles
- Weak interactions and beta decay, Fermi current-current theory and applications to weak decays
- Construction of a unified electroweak $SU(2) \times U(1)_Y$ gauge theory; role of spontaneous symmetry breaking; vector boson masses and couplings; observation of W and Z; Higgs mechanism and observation; other tests, including muon $g-2$
- Fermion couplings and masses; Cabibbo-Kobayashi-Maskawa quark mixing matrix; Glashow-Iliopoulos-Maiani mechanism; $K^0 - \bar{K}^0$ mixing, $B^0 - \bar{B}^0$, and $D_0 - \bar{D}_0$ mixing, $K_L \to \mu^+\mu^-$, CP violation
- Quantum chromodynamics, including early indications of color, deep inelastic scattering and asymptotic freedom, quarkonium, heavy quarks c, b, t; jets, confinement, chiral symmetry breaking
- Residual strong interactions between hadrons; scattering

  Properties of nuclei as bound states of nucleons: masses, radii, stability considerations, types of decays; β, γ, α decays; nuclear reactions; models for nuclei; fission and nuclear power; superheavy nuclei.
- Neutrino masses and lepton mixing as evidence of physics beyond the SM; types of neutrino mass terms, models of neutrino masses, searches for neutrino masses in nuclear and particle decays, neutrinoless double beta decay, theory and experiments on solar and atmospheric neutrinos, accelerator neutrino experiments, reactor antineutrino experiments

- Problems/mysteries in SM, including explanation for gauge group and values of gauge couplings, charge quantization, origin and values of fermion masses, three fermion generations, QCD versus electroweak scale, electroweak versus GUT and quantum gravity scales, hierarchy problem in Higgs sector, strong CP problem, dark matter, etc.
- ideas for physics beyond the SM: grand unified theories and searches for baryon number violation; supersymmetry; dynamical EWSB; constraints on physics beyond the SM.

The university requires us to list expected Learning Outcomes for all courses. The Learning Outcomes for PHY 612 are that the students:

- should gain a comprehensive working knowledge of the Standard Model of particle properties and interactions at an advanced level
- should understand quantitatively the extensions of the original Standard Model to explain nonzero neutrino masses and lepton mixing, including experimental results and theoretical implications
- should know about the questions that the Standard Model does not answer or explain, current ideas on possible physics beyond the Standard Model, and current constraints from searches for new physics