Elementary Particle Physics (Physics 225b)

Syllabus
Winter 2015

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Credit: Sergio Cittolin/CERN

Goals of Physics 225b

In Physics 225b, we will continue the development of gauge field theories and their applications to particle interactions. Some time will be devoted to quantum chromodynamics (QCD), where the non-abelian structure of the SU(3) color gauge group generates phenomena that are strikingly different from those in quantum electrodynamics. But the main focus will be the electroweak interactions, which are responsible for some of the most remarkable phenomena in elementary particle physics. These include the transformation of quarks and leptons from one flavor to another; a host of processes involving neutrinos, such as neutrino oscillations andneutrino interactions in the sun and in supernova explosions; the violation of C, P, T, and CP symmetries; and the phenomenon of electroweak symmetry breaking and the Higgs boson.

The unified theory of the electromagnetic and weak interactions – the electroweak theory– is able to accommodate the three massive gauge bosons of the weak interactions, the W^+, W^-, and the Z, and the single massless gauge boson of the electromagnetic interaction, the photon. The Higgs sector is where this magic happens. With the discovery of "a particle with properties consistent with a Higgs boson" in July 2012, particle physics has entered a new era. We don't know yet whether this observation is consistent with the simplest Higgs scenario, or what we will discover next. But our expectation that the TeV energy scale is critical for understanding the fundamental strucure of matter is being confirmed. The exploration of this energy scale is just beginning.

On Learning Particle Physics

Particle physics is an enormous subject, and in spite of its remarkable coherence, it is quite difficult to learn. Like quantum mechanics, it requires at least "two coats of paint" for many people. As you progress through the subject, **I urge you to go back and review earlier material**; you may well find that some of the earlier results will make much more sense when viewed in a broader context. In addition, it is well worth consulting a variety of different textbooks. I have provided a list of some of the most useful books with this syllabus.

One aspect of this material that some students aren't used to is that it is extremely helpful for you to remember (i.e., to memorize) the qualitative/order-of-magnitude results of many of the calculations that we do. This is in contrast to some physics classes, where you solve problems to make sure that you understand the key concepts, but the actual results might not be all that significant in themselves. **Getting in the habit of remembering results helps you to think on your feet and to develop a physical intuition about the "way things work" in particle physics.**

I want to strongly encourage questions in class -- they make things much livelier for all of us. In fact, we will try to schedule two discussion meetings per week.

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Grades, homework, tests, and all that stuff

- Homework will be assigned on Thursday and is due in class on the following Thursday.
- Grading policy:
  1. Homework: 45%
  2. Class participation: 15%
  3. Final exam: 40%
- Textbooks: *Modern Particle Physics,* Mark Thomson (Cambridge U. Press, 2013) and *Gauge Theories in Particle Physics: A Practical Introduction*, Fourth Edition (2 volume set), Ian J. R. Aitchison and Anthony J. G. Hey (CRC Press, 2012). The book by Thomson will be the primary text, but I also strongly recommend Aitchison and Hey.
- Class time: Tues and Thurs, 2:00 to 3:15 PM
- Class materials will be available on GauchoSpace
- Class location: Phelps 1444
- Office hours: we will schedule two office hour/discussion sections per week (in my office, 5111 Broida). Ideally, at least one of these will be at a time when everyone can come.

Some books on particle physics

- Collider Physics, V. Barger and R.J.N. Phillips, Addison-Wesley.
- The Higgs Hunter's Guide, J.F. Gunion, H.E. Haber, G. Kane, S. Dawson, Perseus Publishing.
- An Introduction to Gauge Theories and Modern Particle Physics (two volumes), E. Leader and E. Predazzi (Cambridge U. Press).
- Introduction to Elementary Particles, D. Griffiths, Wiley-VCH.
- Gauge Theory of Weak Interactions, W. Greiner and B. Muller, Springer-Verlag.
- Quantum Electrodynamics, W. Greiner, and J. Reinhardt, Springer-Verlag.
- Elementary Particle Physics, O. Nachtmann, Springe-Verlag.
- Concepts of Particle Physics (two volumes), K. Gottfried and V.F. Weisskopf
- Particle Physics: a Comprehensive Introduction, A. Seiden, Pearson.
- Particle Physics and Introduction to Field Theory, T.D. Lee, Harwood Academic Publishers.
- Neutrino Physics, K. Winter, Cambridge U. Press.
- Massive Neutrinos in Physics and Astrophysics, World Scientific.
- The Physics of Particle Detectors, D. Green, Cambridge U. Press.
- Particle Detectors, C. Grupen, Cambridge U. Press.
- Particle Physics, D. Carlsmith, Pearson.
- Gauge Theories in Particle Physics, I.J.R. Aitchison and A.J.G. Hey, Institute of Physics Publishers.

- Gauge Theories of Strong, Weak, and Electromagnetic Interactions, C. Quigg, Benjamin Cummings.
- Quantum Field Theory in a Nutshell, A. Zee, Princeton U. Press.
- Quantum Field Theory, M. Srednicki, Cambridge U. Press.
- Cosmology and Particle Physics, Bergstrom and Goodbar, Wiley.
- Experimental Foundations of Particle Physics, R.N. Cahn and G. Goldhaber, Cambridge U. Press.
- Quantum Chromodynamics, G. Dissertori, I. Knowles, M. Schmelling, Oxford Science Publications.
- Theory and Phenomenology of Sparticles, M. Drees, R.M. Godbole, P. Roy, World Scientific.
- Quarks and Leptons, F. Halzen and A.D. Martin, Wiley.
- Particle Physics in a Nutshell, C. Tully, Princeton U. Press.
- Perspectives on LHC Physics, G. Kane and A. Pierce, World Scientific.
- QCD and Collider Physics, R.K. Ellis, W.J. Stirling, and B.R. Webber, Cambridge U. Press.
- At the Leading Edge: The ATLAS and CMS LHC Experiments, D. Green, ed., World Scientific.
- Weak Scale Supersymmetry: From Superfields to Scattering Events, H. Baer, X. Tata, Cambridge U. Press.
- Gauge Theory of Elementary Particle Physics, T.-P. Cheng and L.-F. Li, Oxford U. Press.
- Supersymmetry: Theory, Experiment, and Cosmology, P. Binetruy. Oxford U. Press.
- Supersymmetry in Particle Physics, I. Aitchison, Cambridge U. Press.
- Particle and Astroparticle Physics, U. Sarker, Taylor & Francis.
- Neutrino Physics, K. Zuber, Institute of Physics Publishers.
- A Modern Introduction to Quantum Field Theory, M. Maggiore, Oxford U. Press.

Physics 225b: preliminary schedule (Winter 2015)

Classes labeled "HEP CONF" will be held in the HEP 5th floor conference room, not in the usual classroom.

Class	Date	Topics	Reading Thomson = T Aitchison & Hey = AH
1	Tues, 6 Jan	Group theory review; Lie groups; symmetries and representations.	T: C9 AH: 12, Appendix M
2	Thurs, 8 Jan	Flavor symmetries of the strong interaction: global SU(2) and SU(3) symmetries	T: C9, Appendix F AH: 12
3	Tues, 13 Jan	Quantum Chromodynamics (strong interaction) and SU(3) gauge symmetry	T: C10 AH: 13
4	Thurs, 15 Jan	Quantum Chromodynamics (strong interaction)	T: C10 AH: 14
5	Tues, 20 Jan	Charged current weak interactions; muon decay	T: C11 AH: 20
6	Thurs, 22 Jan	Charged pion decay (and similar decays of other ground-state pseudoscalar mesons)	T: C11 AH: 20
7	Tues, 27 Jan	P- and C-violating effects in weak interaction processes	T: C11 AH: 20
8	Thurs, 29 Jan	Neutrino scattering processes; charged currents and neutral currents	T: C12 AH: 20
9	Tues, 3 Feb	Neutrino oscillations	T: C13 AH: 21.4
10	Thurs, 5 Feb	Neutrino oscillations	T: C13 AH: 21.4
11	Tues, 10 Feb **HEP CONF**	Difficulties with weak interaction phenomenology	T: C15, C16 AH: 22
12	Thurs, 12 Feb **HEP CONF**	Constructing the SM (I): non-abelian gauge theory and QCD	T: C15, C16 AH: 22
13	Tues, 17 Feb	Constructing the SM (II): electroweak interactions	T: C15, C16 AH: 22
14	Thurs, 19 Feb	Constructing the SM (III): electroweak interactions	T: C15, C16 AH: 22
15	Tues, 24 Feb	Constructing the SM (IV): electroweak interactions	T: C15, C16 AH: 22
16	Thurs, 26 Feb	Constructing the Standard Model (V): Higgs mechanism	T: C17 AH: 22
17	Tues, 3 Mar	Constructing the Standard Model (VI) Higgs mechanism	T: C17 AH: 22

18	Thurs, 5 Mar	Higgs mechanism and the Higgs boson	T: C17 AH: 22
19	Tues, 10 Mar	Discovery of the/a Higgs boson	T: C17 AH: 22
20	Tues, 12 Mar	Fun with supersymmetry	T: C18
Final exam		Tues March 18, 4-7 PM	