Gauge Theories & Particle Physics

Physics 539 | Spring Semester 1997 | Chris Quigg

February 3, 1997

Principal Text: C. Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions* (Addison-Wesley, Reading, Massachusetts, 1983).

Recommended: I. J. R. Aitchison and A. J. G. Hey, *Gauge Theories in Particle Physics: A Practical Introduction* second edition (Adam Hilger, Bristol, 1989).
L. B. Okun, *Particle Physics: The Quest for the Substance of Substance* (Harwood Academic Press, New York, 1985).

Field Theory Basics: F. Mandl and G. Shaw, *Quantum Field Theory* (Wiley, New York, 1984).

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Recommended Reading:
Okun, Chapter 1.
Gauge Theories, Chapters 1 and 2.
E. L. Hill, *Rev. Mod. Phys.* **23**, 253 (1953).

Cultural Reading:
C. Quigg, "Elementary Particles and Forces," *Sci. Am.* **252**, (April, 1985), p. 84.
H. Harari, "The Structure of Quarks and Leptons," *Sci. Am.* **248**, (April, 1983), p. 56.
J. R. Rees, "The Stanford Linear Collider," *Sci. Am.* **261**, (October, 1989), p. 58.
S. Myers and E. Picasso, "The LEP Collider," *Sci. Am.* **263**, (July, 1990), p. 54.
L. M. Lederman, "The Tevatron," *Sci. Am.* **264**, (March, 1991), p. 48.
J. Huth, "High Energy Physics — The Road Ahead," *Am. Sci.* **82**, 326 (1994)
B. Carithers and P. Grannis, "Discovery of the Top Quark," SLAC *Beam Line* **25,** No. 3, p. 4 (Fall 1995). The entire issue is available in PDF format at
`http://www.slac.stanford.edu/publications/beamline/95iii.pdf.`

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If you do not already own the 1996 *Review of Particle Physics* [*Phys. Rev. D***54**, 1 (1996)] and the *Particle Physics Booklet*, send an e-mail request to `pdg@lbl.gov`. You may instead write to Particle Data Group, MS 50-308, Lawrence Berkeley Laboratory, Berkeley, CA 94720, to request a copy. There is no charge. The PDG's WWW server is at `http://www-pdg.lbl.gov.`

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Course information, including class schedules and assignments, will be available on the World Wide Web. Point your web client to `http://lutece.fnal.gov/Princeton/.`

Problems (due February 13, 1997)

1. Consider bound states composed of a b-quark and a $\bar{b}$-antiquark. For $(b\bar{b})$ composites,
(a) Show that a bound state with orbital angular momentum L must have quantum numbers
$$C = (-1)^{L+S} \quad P = (-1)^{L+1},$$
where S is the spin of the composite system.
(b) Allowing for both orbital and radial excitations, construct a schematic mass spectrum of $(b\bar{b})$ bound states. Label each state with its quantum numbers J^{PC}.

2. Consider bound states composed of color-triplet scalars, or squarks (denoted $\tilde{b}$) and anti-squarks.
(a) Show that a $(\tilde{b}\bar{\tilde{b}})$ bound state with angular momentum L (i.e., an orbital excitation) must have quantum numbers
$$C = (-1)^L; \quad P = (-1)^L.$$
(b) Allowing for both orbital and radial excitations, construct a schematic mass spectrum of $(\tilde{b}\bar{\tilde{b}})$ bound states. Label each state with its quantum numbers J^{PC}. How does the spectrum of squarkonium differ from that of quarkonium?

3. (a) Using the Feynman rules given in Appendix B.5 of *Gauge Theories*, compute the differential cross section $d\sigma/d\Omega$ and the total (integrated) cross section $\sigma \equiv \int d\Omega(d\sigma/d\Omega)$ for the reaction $e^+e^- \to \mu^+\mu^-$. Work in the center of momentum frame, and in the high-energy limit (where all the masses may be neglected). Assume that the colliding beams are unpolarized, and sum over the spins of the produced muons.
(b) Look up the original evidence for quark–antiquark jets in the inclusive reaction $e^+e^- \to$ hadrons [G. J. Hanson *et al.*, *Phys. Rev. Lett.* **35**, 1609 (1975)]. Now recompute the differential cross section for the reaction $e^+e^- \to \mu^+\mu^-$, assuming the initial beams to be transversely polarized. See also R. F. Schwitters *et al.*, *ibid.* **35**, 1320 (1975).

4. Define the requirements for an experiment to measure the gyromagnetic ratio of the tau lepton, taking into account the τ-lifetime and the anticipated result $g_\tau \approx 2$. For background, become acquainted with the methods used to measure the magnetic anomalies of the electron [A. Rich and J. Wesley, *Rev. Mod. Phys.* **44**, 250 (1972); R. S. Van Dyck, Jr., P. B. Schwinberg, and H. G. Dehmelt, *Phys. Rev. Lett.* **38**, 93 (1977); R. S. Van Dyck, Jr., "Anomalous Magnetic Moment of Single Electrons and Positrons: Experiment," in *Quantum Electrodynamics,* edited by T. Kinoshita (World Scientific, SIngapore, 1990), p. 322.] and muon [F. Combley, F. J. M. Farley, and E. Picasso, *Phys. Rep.* **68**, 93 (1981); F. J. M. Farley, and E. Picasso, "The Muon $g-2$ Experiments," in Kinoshita's *QED*, p. 479], and the magnetic dipole moments of the nucleons [N. F. Ramsey, *Molecular Beams,* Oxford University Press, Oxford, 1956] and unstable hyperons [L. Schachinger *et al.*, *Phys. Rev. Lett.* **41**, 1348 (1978); L. G. Pondrom, *Phys. Rep.* **122**, 57 (1985). For an interesting new technique, see D. Chen *et al.*, *Phys. Rev. Lett.* **69**, 3286 (1992), and V. V. Baublis, *et al.*, *Nucl. Inst. Meth.* **B90**, 150 (1994)]. Indirect determinations of $(g-2)_\tau$ are discussed by R. Escribano and E. Massó, "Improved Bounds on the Electromagnetic Dipole Moments of the Tau Lepton," (bulletin board: hep–ph/9609423); G. Köpp, D. Schaile, M. Spira, and P. Zerwas, *Z. Phys. C***65**, 545 (1995); M. A. Samuel and G. Li, *Int. J. Theor. Phys.* 33, 1471 (1994).

5. For a free particle moving in one dimension, the Lagrangian is $\mathcal{L} = \frac{1}{2}m\dot{x}^2$. Show that the action S corresponding to the classical motion of a free particle from position $x_1 = x(t_1)$ to position $x_2 = x(t_2)$ is
$$S = \frac{m(x_2 - x_1)^2}{2(t_2 - t_1)}.$$

6. For a harmonic oscillator with Lagrangian $\mathcal{L} = \dfrac{m}{2}(\dot{x}^2 - \omega^2 x^2)$, show that the classical action for a particle that moves from position x_1 at initial time t_1 to position x_2 at final time t_2 is
$$S = \frac{m\omega}{2\sin\omega T}\left[(x_1^2 + x_2^2)\cos\omega T - 2x_1x_2\right],$$
where $T \equiv t_2 - t_1$.