Physics 135b
Problem set number 1
Due Wednesday, January 14, 2004

Notes about course:

- Grade: Homework 100%. We will have a problem set instead of a midterm, another problem set instead of a final.
- Collaboration policy: OK to work together in small groups, and to help with each other's understanding. Best to first give problems a good try by yourself. Don't just copy someone else's work – whatever you turn in should be what you think you understand. Don't look at solutions from earlier year(s), though you can ask people who took it before for advice.
- Text: *Introduction to Elementary Particles*, by David Griffiths, Wiley 1987. I think that this is a good text for the course, though we won't follow it exactly. There are a few quibbles I have with his philosophical points, but they aren't serious. You may be concerned about its 16-year age, but this is not a serious problem for our purposes, and I'll let you know the occasional areas where things have progressed significantly (e.g., the top quark has been found; neutrinos appear to have non-zero mass; the electroweak Z boson has been extensively studied; CP violation has been measured in the decays of B mesons).
- This course is a "culture" course, in the sense that I will try to present material on particle physics that I think any well-educated physicist should have been exposed to. I assume a knowledge of quantum mechanics at the level of Ph 125, and classical mechanics and electromagnetism at the level of Ph 106. It is assumed also that you know special relativity.
- URL: http://www.hep.caltech.edu/~fcp/ph135/
- TA: Tristan McLoughlin, tristanm@its.caltech.edu; hours: Tuesdays 6-8 PM, location: 248 Lauritsen.

For the first week, I want you to read the introductory material in chapters 1-3 of the text. The first two chapters I hope you can treat as "light" reading.

The third chapter is a review of relativistic kinematics – you can skip this if you are already comfortable with it, but please at least browse it to get the notational conventions we will be using. Note that I will deviate from the text in using units where $\hbar = c = 1$. I do this not to confuse you, but in the hope that it will instill a deeper appreciation of the arbitrary nature of units, and of the utility of making convenient choices of units.

Most of this assignment is reading, but here are some simple problems to get you going (note – "food for further thought" suggestions are not required bits of the assignment, they are merely intended to stimulate your further understanding. However, at the TA's discretion, you might be rewarded with extra credit if you try to address them and he likes your insights):

1. We may give the value of Newton's constant in the forms:

$$\begin{aligned} G_N &= 6.67 \times 10^{-11}\,\mathrm{m^3 kg^{-1} s^{-2}}, && (1) \\ &= 6.71 \times 10^{-39}\,\mathrm{GeV^{-2}}. && (2) \end{aligned}$$

   Show that (2) follows from (1). This is an opportunity to try to get used to using $\hbar = c = 1$ units. You may use, *e.g.*, 10^{-13} cm = 1 fm, and 197 MeV-fm ≈ 1 (you are encouraged to convince yourself of these facts). Once you get used to this system of units, and remember a few of the conversion constants such as these, obtaining numerical results is no longer a chore.

2. Problem 1.3 in text. This is another chance to use $\hbar = c = 1$ units, and make your life easy.

3. Problem 1.14 in text. Griffiths doesn't really mean **all** of the possible baryon species, which is a very large number when you include the spin, orbital angular momentum, and radial degrees of freedom. Instead, he is just asking for the different possible ways of putting three quarks of types u, d, s, and c together considering only flavor.

4. Units and Parameters: Let us investigate a bit the notion of counting parameters, and the possibility of absorbing some of these into a suitable choice of units. Consider a physical model in which we have electrons of mass m_e and charge $-e$. We adopt the assumption that the speed of light is infinitely faster than any electron motion. There may be other particles (call them "protons") of opposite charge (e),

which in our model are taken as infinitely heavy and motionless with respect to each other. We'll work in the rest frame of the protons.

The prototype problem we wish to consider is one in which there is one electron and one proton. In the typical introductory quantum mechanics course, the physics of this system is described by the time-dependent Schrödinger Equation:

$$i\hbar\frac{\partial}{\partial t}\psi(\mathbf{x},t) = -\frac{\hbar^2}{2m_e}\nabla^2_{\mathbf{x}}\psi(\mathbf{x},t) - \frac{e^2}{|\mathbf{x}|}\psi(\mathbf{x},t) \tag{3}$$

There are three parameters in this equation: Planck's constant (over 2π), $\hbar$; the electron mass, m_e; and the proton charge, e.

Somewhere along the way, we need to decide what units we are using. It seems natural to choose to measure mass in units of the electron mass. This eliminates one parameter from the equation. But we still need to pick units of distance and time: Find a choice of units for distance and for time so that the time-dependent Schrödinger Equation is parameter-free.

Food for further thought: We've just done the one-electron Hydrogen atom – does this choice of units also give parameter-free predictions for more complicated systems of electrons and protons? If so, we see that to a rather good approximation, a substantial bit of chemistry can be described with no free parameters.

More food for further thought: We presumably need to include the Pauli exclusion principle when describing systems of more than one electron in this model. But what about the dynamical effects of spin, or, for that matter, magnetism?

5. In QED (*i.e.*, neglecting weak, strong, gravity interactions), is it possible for light to scatter light? If not, explain. If yes, give an example of a Feynman graph for this process, to lowest order. The question is, can we have a non-trivial elastic scattering: $\gamma\gamma \to \gamma\gamma$? How does this result compare with classical electromagnetism (i.e., Maxwell's equations)?