PHYS 3717: Particle Physics

https://homiller-hep.net/teaching/2026-2/

Homework 1

Deadline: September 8, 2026 (in class)

Problem 1: Planck Units

Newton's gravitational constant is $G_N = 6.67 \times 10^{-11}\,\mathrm{m}^3\,\mathrm{kg}^{-1}\,\mathrm{s}^{-2}$. Define a mass, length and time scale by combining appropriate powers of G_N, c and $\hbar$. These are the so-called Planck mass, Planck length, and Planck time. Compute their values in natural units (with $\hbar = c = 1$) and in SI units.

Problem 2: Natural Units

Estimate the kinetic energy of a 5 mg mosquito flying at a speed of 1 m/s and express it in GeV. What is the approximate kinetic energy per nucleon for a mosquito? How does this compare to the energy of protons at the LHC?

Problem 3: Strengths of Forces and Dimensional Analysis

(a) Compute the gravitational force between a pair of electrons separated by 1 fm. Compare this to the electrostatic force between the electrons.

(b) The Z boson is one of the mediators of the weak force, and has mass $M_Z c^2 = 91.1876$ GeV.[1] Due to its mass, it mediates a finite range weak force between electrons that is described by a potential function of the Yukawa type:

$$V(r) = a_Z k_e e^2 \frac{\exp(-r/\lambda_Z)}{r} \tag{1}$$

where $k_e = 8.988 \times 10^9$ kgm^{3}s^{-2}C^{-2} is Coulomb's constant, $|e| = 1.602 \times 10^{-19}$ C is the magnitude of the electron's electric charge, and $a_Z \sim 1.14$ is a constant stemming from the Z boson coupling to the electron. The length scale, λ_Z is the reduced Compton wavelength of the Z boson, which in natural units (with $\hbar = c = 1$) is given by $\lambda_Z = 1/M_Z$.

(i) Numerically estimate the reduced Compton wavelength of the Z boson, providing your answer in natural units and then converting to SI units.

(ii) Derive the force law from the potential above, and estimate the force between a pair of electrons separated by 1 fm.

(iii) Compare this to the electrostatic force between the electrons. How would this comparison change as you moved the electrons closer and closer together?

[1] This is another quantity that you should know how to look up on the PDG; see Problem 4.

Problem 4: Mesons and Baryons in the PDG

(a) Consider the lightest three quarks $q = (u, d, s)$ (up, down, strange) with electric charges (in units of $|e|$) $Q_u = +2/3$, $Q_d = -1/3$ and $Q_s = -1/3$, respectively. Due to the confining properties of the strong force, these particles appear in nature as bound states of a quark-antiquark pair known as a meson, or as a triplet of three quarks (not antiquarks) known as a baryon. Enumerate all meson ($q\bar{q}$) and baryon (qqq) combinations that can be constructed from these three quarks, and determine their respective electric charges.

(b) Visit the Particle Data Group Website, `https://pdglive.lbl.gov`. This is a comprehensive resource of information about particles and their properties.[2] Explore the particle tables under the following headings: **Light Unflavored Mesons**, **Strange Mesons**, N **Baryons**, Λ **Baryons**, Σ **Baryons**, Ξ **Baryons**, and Ω **Baryons**. For each of the meson and baryon combinations you found in part (a), try to identify at least one corresponding particle in the PDG tables.

(c) How many different meson ($q\bar{q}$) and baryon (qqq) combinations can be made with n quark flavors? The Standard Model has $n = 6$ flavors of quarks (u, d, s, c, b, t). Based on your result, how many types of mesons and baryons should exist? Speculate as to why we do not see that many in the PDG tables.

[2]It also contains numerous reviews on topics in particle physics, which are a great resource both at the level of this class and for active research.