Département de physique nucléaire et corpusculaire
Section de Physique
Université de Genève

Semestre de printemps 2023

ADVANCED PARTICLE PHYSICS II

http://dpnc.unige.ch/∼bravar/PPA2

Exercises - $1^{\rm st}$ Assignment

Distributed: February 21, 2023
To be returned: March 2, 2023

Relativistic Kinematics

1. Calculate the threshold energy for the reaction $p + p \rightarrow p + p + \bar{p} + p$, where the target proton is at rest. Repeat the calculation for protons bound in a nucleus N and that have a Fermi momentum p_f of 200 MeV/c. Comment on the result!

2. Imagine a supernova 100,000 light years away emitting a neutrino burst. There are three types of neutrinos emitted at the same time, but with different masses: $m_1 = 0.01$ eV, $m_2 = 0.1$ eV, and $m_3 = 1$ eV. Let the neutrino energy be 2 MeV. Calculate the arrival time differences between the different neutrino species.

3. Find the threshold ν_μ (ν_τ) energy for the inverse muon (tau) decay $\nu_\mu + e \rightarrow \mu + \nu_e$ assuming that the target electron is at rest. Why is the threshold energy so large?

4. One way of obtaining high energy intense γ beams is to backscatter a laser beam off an electron beam (i.e. at $180°$). Let the energy of the electron beam $E_{el} = 20$ GeV and the wavelength of the laser beam $\lambda = 696$ nm. What is the backscattered photon energy?

Vacuum Structure

5. Derive the expression for the Casimir force per unit area (based on dimensional arguments only!)
$$\frac{\mathrm{d}F}{\mathrm{d}S} = -\frac{\pi^2}{240}\frac{\hbar c}{L^4} \ ,$$
where L is the separation between two infinite conducting parallel plates using dimensional arguments (i.e. ignore the constant factor $\pi^2/240$). Show that the Casimir force from the vacuum energy of fermions has opposite compared to the vacuum energy of bosons.

   It has been suggested that geckos use tha Casimir force to climb walls. What do you think?

6. Derive the phase shift $\Delta\varphi_{AB}$ in the Aharonov-Bohm effect

$$\Delta\varphi_{AB} = \frac{q}{\hbar}\Phi_B \ ,$$

where Φ_B is the magnetic flux through the *loop* delimited by two different paths.

Miscellanea

7. Do we need to take into account gravity in particle accelerators? Explain!

8. Two protons are "confined" to a distance of 2 fm (center to center). Compare the electrostatic repulsion energy to the Fermi motion energy ϵ_F. Derive the minimum binding energy for these two protons.

9. Suppose we interpret the electron as a solid sphere of radius r and mass m, spinning with angular momentum $\frac{1}{2}\hbar$. What is the speed of a point on its equator? Experimentally $r < 10^{-16}\ \mathrm{cm}$. What is the equatorial speed? Does it make sense at all?

10. Express the gravitational constant G_N in natural units.