

Massachusetts Institute of Technology

Department of Physics

Course: 8.701 — Introduction to Nuclear and Particle Physics

Term: Fall 2020

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Problem Set 1

handed out September 10th, 2020

Problem 1: Particles [20 points]

Detailed information on particle properties (e.g., masses, decays, etc.) can be found in the Particle Data Group (PDG) collection: pdg.lbl.gov (see Particle Listings). This is a very useful resource. Let's start to get familiar with some common particles. Look up the following particles: π^\pm , π^0 , K^\pm , K_S^0 , K_L^0 , μ^\pm , e^\pm , proton, and neutron. For each particle, write down the particle's mass, lifetime, and main decay mode (the largest one). How far would each particle travel before decaying on average assuming its speed is c but ignoring time dilation?

Problem 2: Pion Decay [20 points]

Charged pions, π^+ (π^-), can decay to electrons as well as to muons and the corresponding neutrinos. In this decay, the parity violation of the weak interaction is maximal. All arguments hold for π^+ and π^- .

a)

Prepare a sketch of the pion decay at rest noting the momentum vectors as well as the spin of the involved particles. Using the sketch, discuss why you expect maximal parity violation of the weak interaction in pion decays. Following this discussion, which branching fraction is larger? Include your reasoning in the answer.

b)

Show the following relation for momentum and energy, assuming that neutrinos are massless:

$$p_\ell = \frac{m_\pi^2 - m_\ell^2}{2 m_\pi}$$
$$E_\ell = \frac{m_\pi^2 + m_\ell^2}{2 m_\pi},$$

with $m_\pi = 139,57 \text{ MeV}$ the mass of the pion and $m_\ell = 105,66 (0.511) \text{ MeV}$ the mass of the muon (electron).

Problem 3: Higgs Boson branching fractions [xx points]

The coupling of the Higgs boson to fermions is proportional to their masses. The partial width is then proportional to the coupling squared. Calculate Higgs boson branching fractions assuming (simplifying) that only decays to bottom and charm quarks as well as to taus and muons are possible.

Problem 4: Discrete symmetries [20 points]

Discuss how the following properties translate under parity (P) and time reversal (T) operations:

a)

Position vector, \vec{r} .

b)

Momentum vector, \vec{p} .

c)

Angular momentum vector, \vec{L} .

d)

Spin, \vec{s} .

e)

Static electric field, \vec{E} .

f)

Static magnetic Field, \vec{B} .

g)

Potential energy of an electric dipole from particle spin in a static electric field, $\vec{s} \cdot \vec{E}$.

h)

Potential energy of a magnetic dipole from particle spin in an static magnetic field, $\vec{s} \cdot \vec{B}$.

Problem 5: Conservation law and interaction [20 points]

For which of the following interactions (electromagnetic, weak, and strong) do the following conservation laws hold?

a)
Lepton number conservation.

b)
Strong isospin, T_3 .

c)
Strangeness, S .

d)
Parity conservation.

e)
 CP -conservation.

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