Physics 457 Hw 1

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Due: 01-19-2022

Problem 1.

Make the following unit conversions, and show all work. Note that this tests how you use natural units where $c = \hbar = k_B = 1$. Thus, there is one fundamental dimension, which we can take to be energy and express it in GeV to various powers.

a) 1 GeV, in joules (energy)

b) 1 GeV, in Kelvin (temperature)

c) 1 GeV, in kilograms (mass)

d) 1 GeV^{-1}, in meters (length)

e) 1 GeV^{-1}, in seconds (time)

f) 1 GeV^4, in kg/m^3 (mass density)

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a) $1\ GeV = 1.602 \times 10^{-10}\ J$

b) $k_B = 8.617333262 \times 10^{-5} eV/K = 1 \rightarrow 8.617333262 \times 10^{-14}\,\text{GeV} = 1K \rightarrow$ $1\,\text{GeV} = 1.16045 \times 10^{13} K$

c) $E = mc^2$ so $E/c^2 = m \rightarrow$ $1\,\text{GeV} = 1.783 \times 10^{-27} kg$

d) $E = \frac{hc}{\lambda}$ so $1\,\text{GeV}^{-1} = \frac{\lambda}{hc} \rightarrow \lambda =$

Problem 2.

Unstable particles appear to live longer if moving, therefore can travel a longer distance after creation. Consider the following problems and calculate the flight distances.

1. Calculate the flight distance of a muon with 100 GeV energy. Note that the muon lifetime (in its rest frame) is $2.2\mu s$.

2. Calculate the flight distance of a B^+-meson with 20 GeV energy if its lifetime is $1.6x10^{-12}$ s and its mass is 5.38 GeV.

3. Pions are produced in the upper atmosphere when a proton from outer space hits a proton in the atmosphere. The pions then decay into muons:

$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

   But the lifetime of the pion (2.6×10^{-8} s) is much shorter than that of the muon. If the pion is produced at 800 meters above the ground, can it reach the ground if its speed is 0.998c?

Problem 3.

Antiprotons were first created at Lawrence Berkeley National Lab (LBL) in 1955 by a proton beam hitting a proton target with the following reaction:

$$p + p \rightarrow 3p + \overline{p}$$

What is the minimum total energy E of the proton beam to allow this reaction? Please give your answer in unit of proton mass m_p. (Hint: using center-of-mass energy E_{CM} conservation, and assume the final particles are produced at rest.)
