Name:

PHYSICS 360 FALL 2019: HONORS PHYSICS III

MIDTERM 1. *Oct 2, 2019*

▷ **100 points**

You have 50 minutes to work on the exam. Closed-book. There are some physical constants listed at the bottom of this page. You are allowed to use a single letter-sized sheet of paper with your own handwritten notes.

Calculators are allowed and recommended, but only calculators without communication skills (no cell phones, computers, tablets, iPads etc. Internet access is not allowed).

To get full credit you have to show the details of your work and calculations. Explain your reasoning in words.

Good luck!

Problem	Points	
1	40	
2	25	
3	35	
total	100	

Physical constants

1eV$= 1.602 \cdot 10^{-19}$J	$c = 3.0 \cdot 10^8$m/s	
$m_{\text{electron}} = 511$ keV$/c^2$	$m_{\text{proton}} = 938.2$ MeV$/c^2$	$m_{\text{neutron}} = 939.6$ MeV$/c^2$
$1\,$keV $= 10^3$eV	$1\,$MeV $= 10^6$eV	$1\,$GeV $= 10^9$eV

Problem 1. (25 points)

(a) Suppose a photon (which is a light-quanta that travels at the speed of light c) has energy E. What is its momentum expressed in terms of the energy E?

$$p = \frac{E}{c}$$

(b) Lightning hits both ends of a train car at the same time as seen by an observer at rest at the train station. The train is moving at speed u relative to the train station. The train conductor is in the middle of the train car. What does he see?

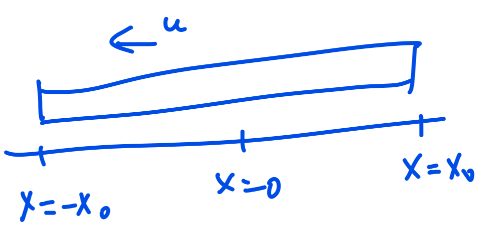
- lightning strikes both ends of the train car simultaneously
- lightning strikes first at the front of the train car
- lightning strikes first at the back of the train car

(c) Set up a *calculation* to prove your answer from part (b) directly using the Lorentz transformations.

$t=0$ happens

$t' = \left(\frac{u}{c^2} x_0\right)\gamma$ end of the car

$t' = -\left(\frac{u}{c^2} x_0\right)\gamma$ front of the car



(d) Describe why it is impossible to accelerate a particle that is going at speed $v_0 < c$ to a speed v equal to or greater than c. You may NOT use the phrase "relativistic mass".

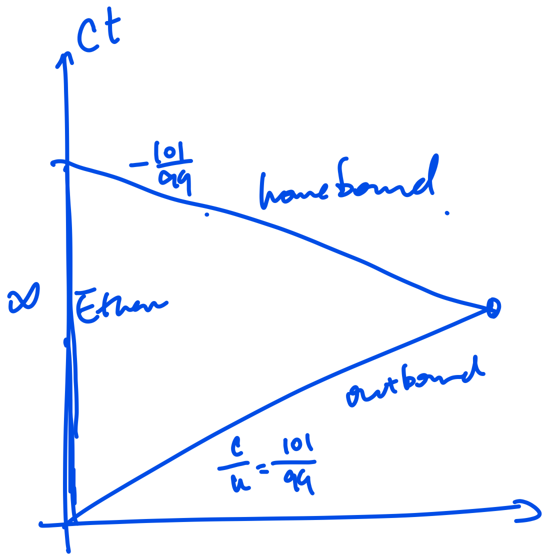
particle moving at speed of light must be massless as we proved in HW using rel-momentum and rel-energy. and massless particle can only move in speed of light. $\Rightarrow$ cannot "accelerate" a particle from $v_0 < c$ to c

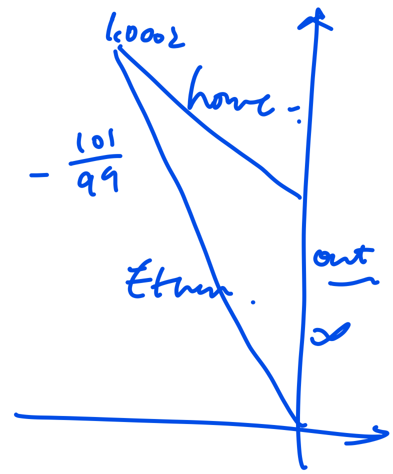
$\Delta KE \sim \infty$ when we accelerate a particle from rest to c

Problem 2. (25 points)

Recall the Twin Paradox in the form we studied in Discussion and Lecture. Ryan travels at speed $u = \frac{99}{101}c$ to a distant star where he promptly turns around and travels home at the same speed to his brother Ethan on Earth. In Ryan's rest frame the outbound trip to the star takes 20 years.

(a) Draw a spacetime diagrams that show the *whole trip*, outbound and return, BOTH in Ethan's rest frame S (as we did in class) and in the rest frame S' of Ryan's outbound trip. Label both Ryan's and Earth's worldlines clearly.





(b) Give the values of the slopes of each of Ryan's and Ethan's worldlines in BOTH of your spacetime diagrams S and S'.

$$V_x' = \frac{V_x - u}{1 - \frac{uV_x}{c^2}} = \frac{-\frac{99c}{101} - \frac{99c}{101}}{1 + \frac{\left(\frac{99}{101}c\right)^2}{c^2}}$$

$$= \frac{-\frac{198}{101}c}{1 + \left(\frac{99}{101}\right)^2} = -0.9998\,c$$

$$\frac{c}{v} = \frac{-1}{0.9998}$$

$\Rightarrow$ slope $= 1.0002$

Problem 3. (25 points)

The tau particle τ has mass $1777\,\mathrm{MeV}/c^2$. The tau can be produced in the scattering process of an electron (e^-) annihilating with its own antiparticle, the positron (e^+): $e^- + e^+ \to \tau + \tau$.

(a) Suppose the kinetic energy of each τ is $45\,\mathrm{GeV}$. What was the total initial kinetic energy?

$2KE_f = 90\,\mathrm{GeV}$

$2m_\tau c^2 = 3554\,\mathrm{MeV}$

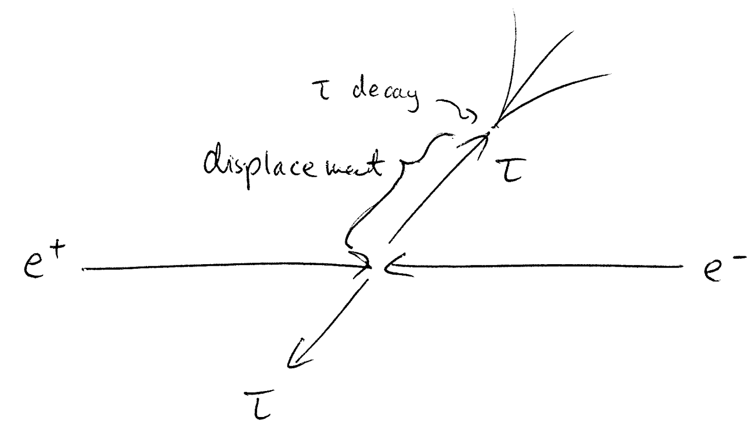
$2m_e c^2 = 1022\,\mathrm{keV}$

$90\,\mathrm{G}^{9}\mathrm{eV} + 3554\,\mathrm{M}^{6}\mathrm{eV} - 1022\,\mathrm{k}^{3}\mathrm{eV}$

$= 9.355 \times 10^{10}\,\mathrm{eV}$

(b) How do you explain the difference between the initial state kinetic energy and final state kinetic energy?

because τ is much heavier than e



(c) Focus now on one of the taus. The tau is a very short-lived with a life time of $2.9 \cdot 10^{-13}s$. After being produced, it will travel a short distance in a detector before it decays to some other particles. (See picture.)

Suppose the resolution in a particle tracking chamber is 50 micrometer $= 50 \cdot 10^{-6}$m. If the kinetic energy of the tau is $45\,\mathrm{GeV}$, *how far does it travel as seen in the lab before it decays?*

Are we able to see the displacement in the tracking chamber of decay vertex away from place where the tau was produced?

$$KE = mc^2\left(\frac{1}{\sqrt{1-v^2/c^2}} - 1\right)$$

$$v = \sqrt{\left(1-\left(\frac{1}{\frac{KE}{mc^2}+1}\right)^2\right)c^2}$$

$$= 0.9992\,c$$

$$T = \gamma T_0 = \frac{1}{\sqrt{1-(0.9992)^2}}\left(2.9\times10^{-13}\,s\right) = 7.25\times10^{-12}$$

$$0.0021 > 50\times10^{-6}$$