Assignment 7; Phys 186 Name ________________

1. (30 points) An important discovery in the 1980s was the W^+ and W^-, which are among the particles responsible for the weak nuclear force. W^+ and W^- are antiparticles of each other, and they each have a rest mass of 80.4 GeV/c^2. Say you want to create a W^+ and W^- pair by a head-on collision of an electron and a positron (e^- and e^+) into each other at speeds close to the speed of light. The rest mass of an electron (and a positron, its antiparticle) is 0.511 MeV/c^2. (Remember: 1 GeV = 1000 MeV.)

(a) As observed from the lab frame of reference, the e^- and e^+ head toward each other with equal and opposite velocities in the collision. What is the minimum time dilation factor γ that the e^- and e^+ must have in order to produce enough energy to create a W^+ and W^- pair at rest?

(b) Say that in the lab frame of reference, the electron traveled 30.0 km at a constant speed corresponding to the γ you calculated in (a). How far did it travel in its own frame of reference?

(c) Calculate how long it took for the electron to travel 30.0 km in the lab frame of reference. Then calculate how long this time interval was in the electrons own frame of reference.

2. **(40 points)** Say you're doing the lab where you accelerated and shot a beam of electrons onto a screen. The mass of an electron is $m_e = 511\,\mathrm{keV}/c^2$.

(a) You accelerated the electrons through a voltage difference of up to 5.00 kV on your dial. At $V_a = 5.00\,\mathrm{kV}$, then, what is the kinetic energy of the electrons in the beam, in units of keV? *Hint:* 1 eV is literally the electron charge magnitude e multiplied by 1 V. Therefore, you shouldn't need any real calculation to get this answer.

(b) What fraction of the speed of light are these electrons traveling? Use $\frac{1}{2}m_e v^2$ for your kinetic energy, as in your homework and the lab.

(c) Recalculate the fraction of the speed of light the electron has, using a more appropriate expression for kinetic energy.

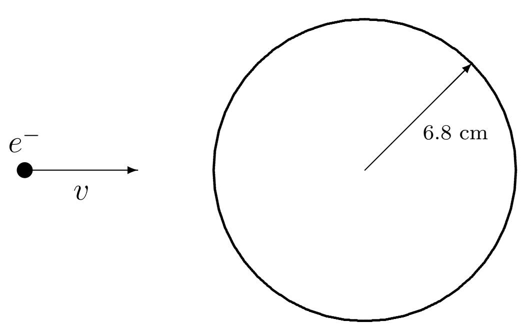
(d) Compare your results in (b) and (c). Do you think relativity was important enough to account for in your lab?

(e) Say you got a lot more expensive equipment that could provide an accelerating voltage of up to $V_a = 500\,\text{kV}$. In that case, what would you calculate the speed of the electrons to be (as a fraction of the speed of light) if you used $K = \frac{1}{2}m_e v^2$?

(f) Redo the calculation for v as a fraction of the speed of light with $V_a = 500\,\text{kV}$, but now using the correct expression for kinetic energy.

(g) Compare your results with different expressions for kinetic energy in (e) and (f) and interpret what they mean.

(h) Again, $V_a = 500\,\text{kV}$. In the lab reference frame, the copper coils with the current providing the magnetic field were circles with a radius of about $R = 6.8\,\text{cm}$. Sketch how the coils look in the electrons' reference frame, and calculate the appropriate dimensions (height, width) for the coil in that frame.



lab frame

electron frame

3. (30 points) Say you're observing light from a distant star. But the star is moving relative to Earth: it is moving directly away from Earth with speed v. Now, light is an electromagnetic wave. In the Earth frame of reference, the waves have period T_E: the star emits wavefronts once every T_E. Since the star is moving away, on Earth, you won't observe the same time interval T_E between wavefronts.

(a) In the Earth frame, during the time interval T_E it takes between emitting wavefronts, how much further will the star have moved away from the Earth?

(b) How much extra time will the next wavefront take to reach the Earth?

(c) The period you you actually observe, T_o, will be T_E plus the extra time you calculated for the wavefront. What is this observed period?

(d) Now, remember that T_E was in the Earth frame of reference. What is T_s, the time between wavefront emissions, in the frame of the star (the source)?

(e) Put everything together: find an equation for T_o in terms of T_s and v/c. (If you want to simplify your expression, note that $(1 - a^2) = (1 + a)(1 - a)$.)

(f) Check your equation. What does it give you when $v = 0$? Is this reasonable? What about when $v = c$? Is that what you'd expect—if the source is moving away from you at $v = c$, would you see any waves?

(g) Let's say that since you know the physics of stars, you know that the star you're observing should be emitting blue light with a wavelength of 450 nm. But what you actually see is red light with a wavelength of 700 nm. What, then, is v/c, the fraction of the speed of light the star is moving away from Earth?

Extra Problems (not graded)

4. (0 points) A cosmic ray collision creates a muon (a subatomic particle) near the top of the troposphere, at an altitude of 9000 m. The muon heads straight towards the surface at a speed of $0.998c$.

(a) In the reference frame of a ground observer, what is the muon's initial distance to the surface? What is the time the muon takes to reach the surface?

(b) In the reference frame of the muon, what is the muon's initial distance to the surface? What is the time the muon takes to reach the surface?

(c) When measured at rest in the lab, the average lifetime of a muon is 2.2×10^{-6} s. Given your answers to (a) and (b), would an average muon make it to the surface, or does it have to be an exceptionally long-lived one? Explain.

5. (0 points) You have a proton and an antiproton at rest on Earth. They annihilate to produce a muon-antimuon pair: $p + \bar{p} \to \mu^- + \mu^+$. The muon heads toward the Moon, 3.8×10^8 m away, and the antimuon is captured by a detector here on Earth. The typical lifetime of a muon is 2.2×10^{-6} s. Will the muon make it to the Moon to be captured by a detector there? A muon's mass is $m_\mu = 1.9 \times 10^{-28}$ kg, or 110 MeV/c^2. A proton's mass is $m_p = 1.7 \times 10^{-27}$ kg or 940 MeV/c^2. The speed of light is 3.0×10^8 m/s. Note:

- Relativistic energy (γmc^2) and momentum ($\gamma m\vec{v}$) are both conserved in this reaction. Show how you use both.
- Solve this using the masses given in MeV/c^2.