ISP220, fall 2021: In-Class Project #10_11; 30 pts ...PLUS! 10 bonus points!

Quarks, Spacetime, and the Big Bang

Tuesday, October 12, 2021

Name: KEY Student # ____________

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1 Simultaneity, 10 points

Figure 1: Sally the flight attendant with great peripheral vision.

Figure 1 shows Sally the flight attendant who's just about to button up a plane for takeoff. Yes, it's empty. Don't ask. Anyhow, she's standing in the middle of the cabin and can see the seatbelt sign at the back and at the front. Those signals are designed to light up at exactly 1 minute before taxiing. And they do.

We are at the gate looking out the window at the plane and somehow we can see through the walls where we observe Sally and the two signs. Don't ask. By the way, they are labeled for all of us: the back sign is B and the front sign is F. Sally is precisely between them. This weird situation is shown in Figure 2.

Figure 2: The plane as viewed from the airport.

Answer (2 points): The plane is sitting still relative to the airport, so $\vec{v} = 0$. Which sign does Sally see light up first? Circle the right answer.

B F [✓ both the same time]

Answer (2 points): The plane is sitting still relative to the airport, so $\vec{v} = 0$. Which sign do we in the airport see light up first? Circle the right answer.

B F [✓ both the same time]

Now the plane starts to taxi to the left.

Answer (2 points): The plane is now moving relative to the airport, so $\vec{v} = 5$ mph, left. Which sign does Sally see light up first? Circle the right answer.

B F [✓ both the same time]

Answer (2 points): The plane is now moving relative to the airport, so $\vec{v} = 5$ mph, left. Which sign do we see light up first? Circle the right answer.

[✓ B] F both the same time

Answer (2 points): Can either of us confirm when something happens simultaneously between two relatively moving inertial frames of reference?

NO

2 Induction, huh?, 10 points

In the now famous galvanometer-coil-magnet demonstration:

Answer (10 points): What was troubling about the circumstance when the coil is stationary and the magnet moves as compared with when the magnet is stationary and the coil moves?

magnet moves: $\vec{B}$ and $\vec{E}$ explain the current

coil moves: only $\vec{B}$ explains the current...
there is no $\vec{E}$ field

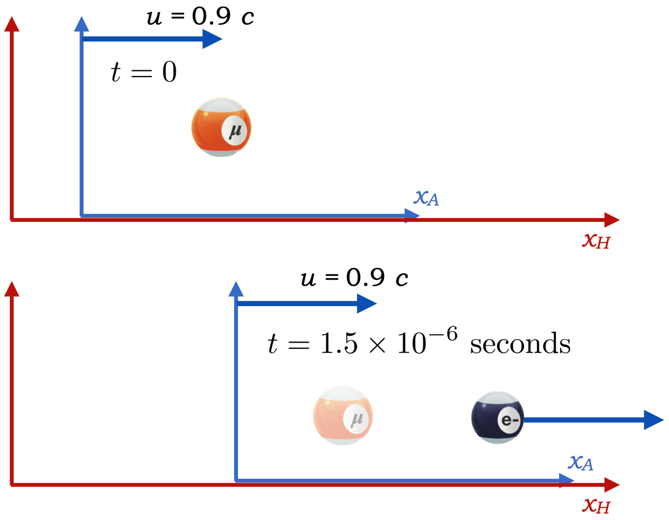

Figure 3: One way out.

3 Muons, 10 points

One of the standard tests, and now tools of Special Relativity is measuring the characteristics of very fast, unstable elementary particles. We've talked about the muon before. A muon is nothing more than a heavy electron, but it seems that Nature insists on permitting all matter to decay until the products of those disintegrations can't get any lighter. So a decay might go like:

$$A \to B \to C \to D \to e$$

After an electron, there's nothing else to decay into...unless the electron is also unstable, but very long lived! We're looking for that!

3.1 Figure 4 is a cartoon of a muon decay.

A muon is produced as a product of a pion decay (see the text!) in the very upper reaches of our atmosphere and streams towards the Earth with a speed that is 90% of that of light. Its lifetime in its frame is 1.5×10^{-6} seconds...1.5 microseconds, which is very long-lived for an elementary particle.

Answer (2 points): What is the muon's β?

$\beta =$ 0.9

Answer (4 points): What is the muon's γ? Feel free to use the tools in QS&BB.

$\gamma =$ 2.3

Answer (2 points): From the muon's point of view, what is its lifetime? That's its "Home" frame, right?

$t_H =$ 1.6×10^{-6} seconds

We're on Earth, so if we observe the muon barreling toward us, that's our Home frame and the muon's own frame is the Away frame from our perspective.

Answer (2 points): What do we observe as the time that the muon survives before it decays?

$t_H =$ 3.45×10^{-6} seconds

$$t_H = \gamma t_A$$
$$= (2.3)(1.6 \times 10^{-6})$$
$$= 3.45 \times 10^{-6}$$

4 Electrons at SLAC, 10 points

The previously named Stanford Linear Accelerator Center (SLAC) was the premier facility built to accelerate electrons to enormous energies and crash them together. Sanford University is one of three universities with their own accelerators, along with Cornell University and MSU.

The acceleration stage is a 3 km long tube containing a string of RF cavities and the speed of those electrons is so high that to an electron, the length of that long tube is only 3 cm long.

Answer (3 points): From the perspective of the electron ~~laboratory~~, what is L_H of the tube in meters?

$L_H =$ 0.03 m

This's tough and worded badly. It should be thought of from the electron's frame ... call it $L_H(e)$. The electron sees the tube as $L_H(e) = 3cm^*$. But the away frame is the lab $L_A(e) = 3000m$. So $L_H(e) = \frac{L_A(e)}{\gamma}$

* the electron sits still in its rest frame and watches the lab going by, shrunk in length.

Figure 4: SLAC's long beamline looking to the east, passing underneath highway 280 with the Stanford University Golf Course just beyond.

Answer (3 points): From the perspective of the ~~laboratory~~ electron, what is L_A of the tube in meters?

$L_A =$ 3000 m

Answer (4 points): What is the relativistic γ that the electron's frame experiences, assuming that we can treat the average speed as constant.

$\gamma =$ 10^5

$L_H = \frac{L_A}{\gamma}$

$\gamma = \frac{L_A}{L_H} = \frac{3000}{0.03}$

One could reason to the right answer, knowing that $\gamma > 1$, so $\frac{3000}{0.03} = 10^5 > 1$. But this is badly written.