53.

CORPUS CHRISTI COLLEGE
SEQUERE DOMINUM

12 ATAR Physics

Special Relativity Test 2016 (5%)

Student name: Soln

1. A spacecraft moving at 95% of the speed of light passes the Earth on a journey to the star Lalande-21185 a distance of 8.29 light years.

In the frame of reference of the spacecraft (experienced by the crew) what time and spatial measurements of the journey are different compared to those measured by an Earth based observer? Which **TWO** statements are correct? **[2 marks]**

a) Length contraction states, '*the path length through space is longer than 8.29 light years*'.
b) Length contraction states, '*the path length through space is shorter than 8.29 light years*'.
c) Time dilation states, '*the clock on earth is moving slower*'.
d) Time dilation states, '*the clock on the spacecraft is moving slower*'.

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In the frame of reference of the Earth what time and spatial measurements of the journey are different compared to those measured by an observer on the spacecraft? Which **TWO** statements are correct? **[2 marks]**

a) Length contraction states, '*the path length through space is shorter than 8.29 light years*'.
b) Length contraction states, '*the path length through space will be 8.29 light years*'.
c) Time dilation states, '*the clock on earth is moving slower*'.
d) Time dilation states, '*the clock on the spacecraft is moving slower*'.

2

2. Explain what is meant by the term, '*inertial reference frame*'. **[1 mark]**

STUDENTS MENTION:
- IT IS NOT ACCELERATING (OR)
- NEWTON'S LAWS ARE OBEYED. ✓

1

5

3. Explain what is meant by the term, '*luminiferous aether*' and what experiment lead to its demise? **[2 marks]**

STUDENTS MENTION:

(1) THE PREVIOUSLY (CLASSICALLY) ACCEPTED MEDIUM FOR EM RADIATION. ✓

(2) PROVED NOT TO EXIST BY THE M & M EXPT. ✓

2

4. State the two postulates of Special Relativity that Einstein used to reject the necessity for the luminiferous aether. **[2 marks]**

(1) NO LAW OF PHYSICS CAN IDENTIFY A STATE IN ABSOLUTE REST. ✓

(2) THE SPEED OF LIGHT WILL ALWAYS BE THE SAME NO MATTER HOW THE LIGHT SOURCE OR OBSERVERS ARE MOVING. ✓

2

5. A student is traveling in a windowless carriage in an exceptionally smooth train moving at constant velocity. Is there any physical experiment she can do in the train car to determine whether is moving? Explain your answer. **[3 marks]**

(1) NO, THERE IS NO SUCH EXPT. ✓

(2) THE WINDOWLESS CARRIAGE IS AN INERTIAL REF FRAME. ✓

(3) THE LAWS OF PHYSICS ARE THE SAME IN ALL INERTIAL REF FRAMES. ✓

3

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6. A student is on a spaceship traveling at 0.5**c** away from a star, at what speed would the starlight pass the student? Explain your answer. **[3 marks]**

STUDENTS MENTION:

(1) WILL ALWAYS PASS AT $3 \times 10^8 ms^{-1}$ (c) ✓

(2) SPEED OF LIGHT IS CONST IN ANY REF FRAME. ✓

(3) ACCORDING TO THE 2nd POSTULATE OF SPECIAL RELATIVITY. ✓

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7. The time dilation effect is sometimes expressed as "*moving clocks run slowly.*"

a) Actually, this effect has nothing to do with motion affecting the functioning of clocks. What then does it deal with? **[2 marks]**

STUDENTS MENTION:

(1) THE CLOCKS ARE NOT AT FAULT THEY ARE CORRECT. ✓

(2) TIME ITSELF IS ACTUALLY MEASURED TO PASS MORE SLOWLY IN MOVING REF. FRAMES. ✓

2

b) Does time dilation mean that time actually passes more slowly in moving reference frames or that it only seems to pass more slowly? Explain your answer and give examples where necessary. **[3 marks]**

STUDENTS MENTION:

(1) TIME ACTUALLY PASSES MORE SLOWLY IN THE MOVING REF FRAME. ✓

(2) IT IS MEASURED TO PASS MORE SLOWLY BY EXPT. ✓

(3) RELEVANT EXPT. ✓

3

8

c) Consider the proposed new Sydney to Perth bullet train that travels at a speed of 0.482**c**. A passenger on the bullet train drops a shiny stainless steel ball bearing from a height of 1.36m.

i. What would be the time measured by the passenger for the ball bearing to fall to the floor? **[2 marks]**

$s = ut + \frac{1}{2}gt^2 \quad (u = 0)$

$\therefore t^2 = \frac{2s}{g} = \frac{2(1.36)}{9.8} = 0.28$ ✓

(2)

$\therefore t = 0.53$ secs. ✓

ii. As the train passes through a level crossing, a stationary observer notices the ball bearing fall to the floor of the train. What would be the time measured by the stationary observer for the ball bearing to fall to the floor? **[5 marks]**

$0.482c = (0.482)(3 \times 10^8) = 1.446 \times 10^8 \text{ ms}^{-1}$ ✓

$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = \frac{1}{\sqrt{1 - \frac{(1.446 \times 10^8)^2}{(3 \times 10^8)^2}}}$ ✓

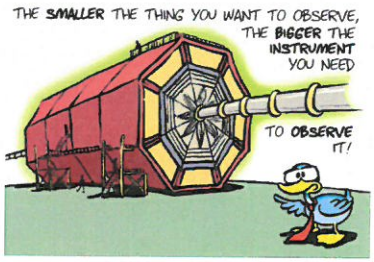
(5)

$\therefore \gamma = 1.14$ ✓

$\therefore t = (0.53)(1.14) = 0.60$ secs ✓ ✓

(7)

8. One of the biggest accelerators in the world is at CERN in Geneva, the site of the Large Electron-Positron (LEP) collider. It is 27 km long and accelerates the electrons (and positrons) to enormous energies in the 50 GeV in energy range.



a) Calculate the '*rest-mass*' energy of a positron. Give your answer in MeV. **[2 marks]**

$E = mc^2 = (9.11 \times 10^{-31})(3 \times 10^8)^2$

$= 8.199 \times 10^{-14}$ J. ✓

$= \underline{0.512 \text{ MeV}}$. ✓

(2)

b) Calculate the relativistic mass of an electron traveling along the particle accelerator with a speed of 0.99**c** **[4 marks]**

$0.99c = (0.99)(3 \times 10^8) = 2.97 \times 10^8 \text{ ms}^{-1}$ ✓

$\gamma = \dfrac{1}{\sqrt{1 - v^2/c^2}} = \dfrac{1}{\sqrt{1 - \dfrac{(2.79 \times 10^8)^2}{(3 \times 10^8)^2}}}$ ✓

(4)

$\therefore \gamma = 7.09$. ✓

$m = \gamma m' = (7.09)(9.11 \times 10^{-31})$

$= \underline{6.46 \times 10^{-30} \text{ Kg}}$. ✓

(6)

c) What is the total energy of an electron traveling along the particle accelerator with a speed of 0.99**c**? **[4 marks]**

$$E_{TOT} = E_{REST} + E_K \quad \checkmark$$

$$= (8.199 \times 10^{-14}) + \tfrac{1}{2}(6.46 \times 10^{-30})(2.97 \times 10^{8})^2 \quad \checkmark$$

$$= 3.67 \times 10^{-13}\ J. \quad \checkmark$$

$$= \underline{2.29\ MeV.} \quad \checkmark$$

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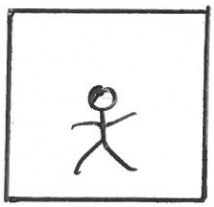
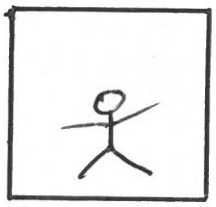
9. Show, **by calculation**, that the speed of light (**c**) is constant in all reference frames. Use a diagram to help explain your answer. **[5 marks]**



STATIONARY



c →

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$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \quad \checkmark = \frac{1}{\sqrt{(8.85 \times 10^{-12})(1.26 \times 10^{-6})}}$$ FROM DATA SHEET.

$$\therefore\ c = \underline{2.99 \times 10^{8}\ ms^{-1}}. \quad \checkmark$$

SINCE, BOTH ϵ_0 & μ_0 ARE EQUAL IN BOTH REF FRAMES, c MUST BE IN BOTH !! ✓

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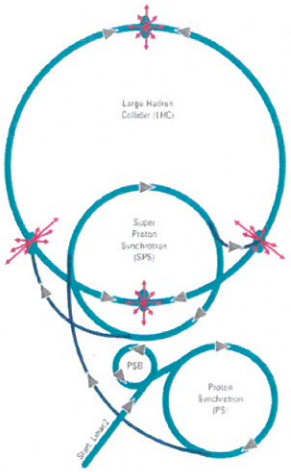
10. To enable detection of the Higgs boson, proton-antiproton collisions were produced at the LHC in CERN, Switzerland. In order to reach the enormous energies required, the particles were accelerated along the 27km circumference of the LHC to reach speeds, 99.999% the speed of light.



a) From the frame of reference of the moving particle, what is the circumference of the LHC? **[5 marks]**

$99.999\%\, c = (0.99999)(3\times10^8) = 2.99997\times10^8\ ms^{-1}$.

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{(2.99997\times10^8)^2}{(3\times10^8)^2}}}$$

$\therefore \gamma = 224$.

(5)

$$\ell' = \frac{\ell}{\gamma} = \frac{27}{224} = 0.12\ km.$$

b) From the frame of reference of the moving particle, what happens to the area bound by the circumference of the LHC tunnel? Explain your answer. **[2 marks]**

STUDENTS MENTION:

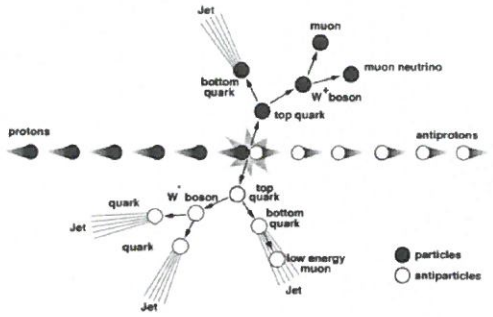
(1) NO CHG IN AREA

(2) LENGTH CONTRACTION WILL ONLY AFFECT LENGTH IN THE DIRECTION THE PARTICLE IS TRAVELING.

(2)

(7)

c) A stationary observer, monitoring the particle beams from the side, noticed that the protons move with velocity of 0.8**c**, while the antiprotons move with a velocity of 0.60**c** in the opposite direction. What is the velocity of the particles, relative to each other? **[4 marks]**



$$u' = \frac{V - u}{1 - \frac{Vu}{c^2}} \qquad V = 0.8c. \qquad u = -0.6c.$$

$$\therefore \quad u' = \frac{(0.8c) - (-0.6c)}{1 - \frac{(0.8c)(-0.6c)}{c^2}}$$

$$= \frac{(0.8c) + (0.6c)}{1 + 0.48}$$

$$\therefore \quad u' = \frac{1.4c}{1.48} = \underline{0.95c.}$$

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