ALL SAINTS' COLLEGE

Ewing Avenue, Bull Creek, Western Australia

Year 12 Physics ATAR	Special Relativity	2016

Time allowed: 50 minutes
Total marks available: 50
Show calculation answers to 3 significant figures

Student Name:_______________________

Question 1 **(5 marks)**

Georgia is in the International Space Station (ISS) orbiting the Earth at a constant speed of roughly 7.66 km s^{-1}. This means that she sees a sunrise and sunset once every 92 minutes.

(a) Is the ISS an inertial frame of reference? Explain your answer. (2)

Description	Marks
No	1
The ISS is not an inertial frame of reference is it is accelerating towards the Earth.	1
Total	2

(b) Considering only special relativistic effects, does an observer at rest on Earth see clocks on the ISS running slower or faster than the same clocks on Earth? Circle your answer and provide an explanation.

Slower Faster

Explanation (3)

Description	Marks
Slower	1
The ISS is moving relative to the observer at rest on Earth and therefore this observer would see events on the ISS taking longer than the same events on Earth. The observer at rest on Earth would therefore see the clocks on the ISS running slow relative to the same clocks on Earth.	1-2
Total	3

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Question 2 **(2 marks)**

State the two postulates of the special theory of relativity.

1.

Description	Marks
The laws of physics are the same for objects moving in inertial frames of reference.	1
The speed of the light is the same for all observers regardless of their motion relative to the light source.	1
Total	2

2.

Question 3 **(5 marks)**

An observer on a spaceship performs an experiment which in their frame of reference takes 25.0 s to complete. The spaceship moves past an observer at rest on Earth at a relative speed of 0.850 c. The observer on Earth also measures the time for the experiment to complete.

(a) Does the observer on the spaceship or the observer on Earth measure the proper time for the experiment? Circle your answer and provide an explanation.

Observer on the spaceship   Observer on Earth

Explanation (2)

Description	Marks
Observer on the spaceship	1
They are at rest with respect to the experiment and therefore they measure the proper time.	1
Total	2

(b) Calculate the time that the experiment takes to complete as measured by the observer at rest on Earth. (3)

Description	Marks
$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{25}{\sqrt{1-\frac{0.850^2 c^2}{c^2}}} = \frac{25}{\sqrt{1-0.850^2}}$	1-2
$t = 47.5\ s$	1
Total	3

Question 4 **(12 marks)**

Earth is subject to a constant bombardment of subatomic particles that can reach energies far higher than that achieved in particle accelerators. These high-energy particles arriving from outer space are mainly (89%) protons – nuclei of hydrogen, the lightest and most common element in the universe.

The very high-energy proton generate huge showers of up to 10 billion secondary particles or more. These particles can be picked up by particle detectors when they spread over areas as large as 20 square kilometres at the surface of the Earth.

For Parts (a) to (c) of this question consider a proton that enters the Earth's atmosphere at a speed of 0.9995 c at a height of 50,000 m relative to an observer at rest on Earth.

(a) Calculate the relativistic momentum of the proton. (3)

Description	Marks
$p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1.67\times10^{-27}\times0.9995\times c}{\sqrt{1-\frac{0.850^2 c^2}{c^2}}}$ $= \frac{1.67\times10^{-27}\times0.9995\times3.00\times10^8}{\sqrt{1-0.9995^2}}$	1-2
$p = 1.58\times10^{-17}\ kg\ m\ s^{-1}$	1
Total	3

(b) Calculate the path length that the proton travels in its frame of reference, between entering the atmosphere and impacting the surface of the Earth. (3)

Description	Marks
$L = L_0\sqrt{1-\frac{v^2}{c^2}} = 50{,}000\sqrt{1-\frac{0.9995^2 c^2}{c^2}}$ $= 50{,}000\times\sqrt{1-0.9995^2}$	1-2
$L = 1.58\ \times10^3\ m$	1
Total	3

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(c) Calculate the time that the proton takes to travel to the surface of the Earth in the reference frame of the observer at rest on Earth. (2)

Description	Marks
$t = d/v = 50{,}000/(0.9995 \times 3.00 \times 10^{8})$	1
$t = 1.67 \times 10^{-4}\ s$	1
Total	2

(d) Another proton enters the upper atmosphere and collides with an oxygen molecule. The collision produces a neutron and several other subatomic particles.

The velocity of the proton after the collision is 0.900 c to the right relative to an observer at rest on Earth. The velocity of the neutron is 0.850 c to the right relative to the proton as shown in the diagram.

Calculate the velocity of the neutron relative to the observer at rest on Earth. (4)

Description	Marks
$u = \frac{v+u'}{1+\frac{vu'}{c^2}} = \frac{0.900c+0.850c}{1+\frac{0.900c \times 0.850c}{c^2}} = \frac{1.750c}{1+0.900 \times 0.850}$	1-3
$u = 0.992\ c\ (2.97 \times 10^{8}\ m\ s^{-1})$	1
Total	4

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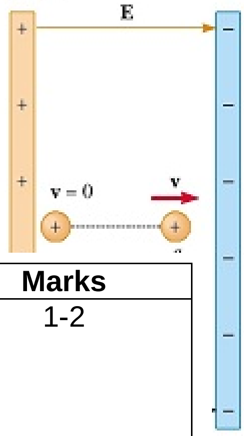
Question 5 **(8 marks)**

A positron is accelerated from rest by a uniform electric field between two charged plates. The relativistic energy of the positron after being accelerated by the charged plates is 1.24×10^{-13} J.



(a) Calculate the final speed of the positron. Note that the positron has the same mass as an electron. (5)

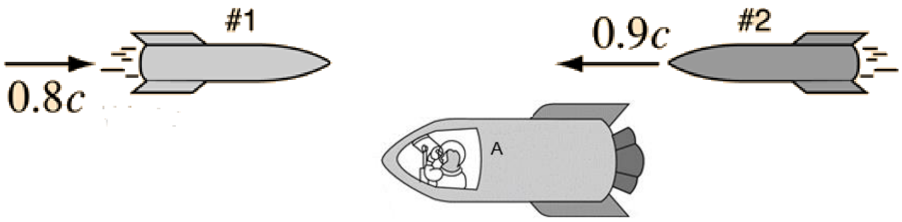
Description	Marks
$E = \frac{m_0 c^2}{\sqrt{1-\frac{v^2}{c^2}}}$ $1.24 \times 10^{-13} = \frac{9.11\times10^{-31}\times c^2}{\sqrt{1-\frac{v^2}{c^2}}}$ $\sqrt{1-\frac{v^2}{c^2}} = \frac{9.11\times10^{-31}\times c^2}{1.24\times10^{-13}}$	1-2
$1-\frac{v^2}{c^2} = 0.661^2$ $= 0.437$	1
$\frac{v^2}{c^2} = 1 - 0.437$ $= 0.563$	1
$v = \sqrt{0.563}c = 0.750\ c$ (2.25×10^8 m s^{-1})	1
Total	5

(b) Calculate the kinetic energy that the positron gains after being accelerated across the gap. (3)

Description	Marks
$KE = E - E_{rest}$ $= E - m_0 c^2$ $= 1.24 \times 10^{-13} - 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$	1-2
$KE = 4.20 \times 10^{-14}\ J$	1
Total	3

Question 6 **(4 marks)**

Spaceship 1 has a velocity of 0.800 c to the right relative to Observer A and Spaceship 2 has a velocity of 0.900 c to the left relative to Observer A.



Calculate the velocity of Spaceship 1, relative to Spaceship 2.

Description	Marks
$u' = \frac{u-v}{1-\frac{vu}{c^2}} = \frac{0.800c - -0.900c}{1-\frac{-0.900c \times 0.800c}{c^2}}$	1-2
$u' = \frac{1.70c}{1+0.72}$	1
$u' = 0.988\ c\ (2.97 \times 10^8\ m\ s^{-1})$	1
Total	4

Question 7 **(3 marks)**

Explain why an object with non-zero rest mass cannot be accelerated to the speed of light.

Description	Marks
With reference to the relativistic energy equation $E = \frac{m_0 c^2}{\sqrt{1-\frac{v^2}{c^2}}}$ as v approaches c the denominator approaches 0. An as the denominator approaches zero the relativistic energy of the particle approaches infinity.	1-2
Therefore for the speed of the particle to reach c the energy added would have to be infinite which means that the particle cannot be accelerated to the speed of light.	1
There are several possible explanations here, i.e. F=ma etc. Accept any reasonable explanation.	
Total	3

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Question 8 **(5 marks)**

Calculate the energy released by the following fusion reaction

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + energy$$

where

- mass of deuterium nucleus = 3.34358 x 10^{-27} kg,
- mass of tritium nucleus = 5.00736 x 10^{-27} kg,
- mass of helium-4 = 6.64466 x 10^{-27} kg,
- mass of neutron = 1.67500 x 10^{-27} kg.

Description	Marks
$\Delta m = m_{products} - m_{reactants}$ $= (6.64466 \times 10^{-27} + 1.67500 \times 10^{-27}) - (3.34358 \times 10^{-27}$ $+ 5.00736 \times 10^{-27}$ $= 8.32 \times 10^{-27} - 8.35 \times 10^{-27}$ $= -3.128 \times 10^{-29}\ kg$	1-3
$E = \Delta mc^2$ $= -3.128 \times 10^{-29} \times (3.00 \times 10^8)^2$	1
$E = -2.82 \times 10^{-12}\ J$ Therefore energy released is $2.82 \times 10^{-12}\ J$.	1
Total	5

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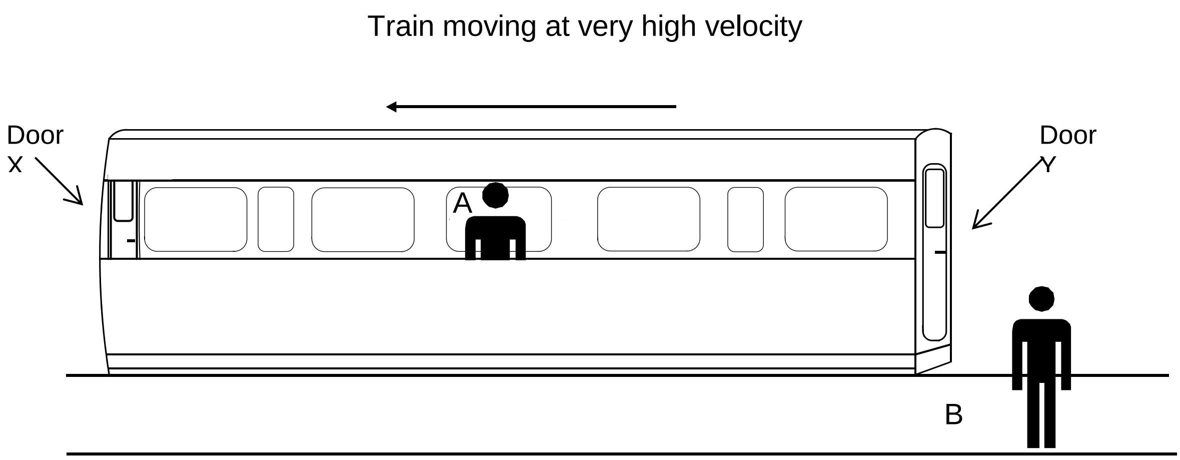
Question 9 **(6 marks)**

Observer A stands at the midpoint of a train carriage. The observer presses once on an infrared remote control that simultaneously sends a photon to Door X and to Door Y. Once a photon reaches a door the door will open. Observer B stands on the platform and watches the train move past her at high velocity to the left.



(a) Does Observer A see Door X open first, Door Y open first or both doors open simultaneously? Circle your answer and provide an explanation.

Door X opens first   Door Y opens first   Simultaneously

(3)

Explanation

Description	Marks
Simultaneously	1
As the photons are emitted in the middle of the carriage and Observer A is at rest with respect to the carriage, Observer A will see the photons reach both doors at the same time. Observer A thus concludes that both doors open simultaneously.	1-2
Total	3

(b) Does Observer B see Door X open first, Door Y open first or both doors open simultaneously? Circle your answer and provide and explanation.

Door X opens first   Door Y opens first   Simultaneously

(3)

Explanation

Description	Marks
Door Y opens first	1
Observer B sees both photons emitted at the same time. However in Observer B's frame of reference the photon moving towards door Y must travel a shorter distance to reach the door as the train is moving towards that photon. Observer B thus concludes that door Y opens first.	1-2
Total	3