Q1. A muon is an unstable particle produced by cosmic rays in the Earth's atmosphere. Muons that are produced at a height of 10.7 km above the Earth's surface, travel at a speed of $0.996c$ toward Earth, where c is the speed of light. In the frame of reference of the muons, the muons have a half-life of 1.60×10^{-6} s.

(a) (i) Calculate how many muons will reach the Earth's surface for every 1000 that are produced at a height of 10.7 km.

number of muons ....

(3)

(ii) Which of the following statements is correct? Tick (✓) the correct answer.

	✓ if correct
For an observer in a laboratory on Earth, the distance travelled by a muon that reaches the Earth is greater than the distance travelled by a muon in its frame of reference	
For an observer in a laboratory on Earth, time passes more slowly than it does for a muon in its frame of reference	
For an observer in a laboratory on Earth, the probability of a muon decaying each second is lower than it is for a muon in its frame of reference	

(1)

(b) (i) Show that the total energy of an electron that has been accelerated to a speed of $0.98c$ is about 4×10^{-13} J.

(2)

(ii) The total energy of an electron travelling at a speed of $0.97c$ is 3.37×10^{-13} J. Calculate the potential difference required to accelerate an electron from a speed of $0.97c$ to a speed of $0.98c$.

potential difference = ... V

(1)
(Total 7 marks)

Q2. One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(a) Explain what is meant by this postulate.

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(1)

(b) State the other postulate.

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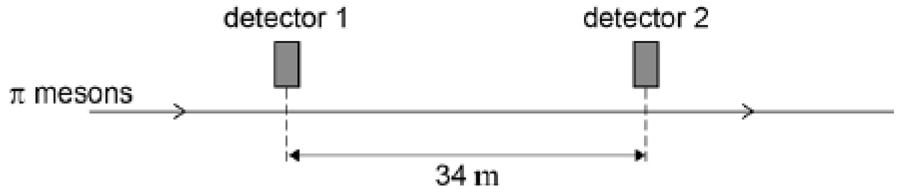
(1)

(c) Two detectors are measured to be 34 m apart by an observer in a stationary frame of reference. A beam of π mesons travel in a straight line at a speed of 0.95 *c* past the two detectors, as shown in the figure below.



Calculate the time taken, in the frame of reference of the observer, for a π meson to travel between the two detectors.

time = ...

(1)

(d) π mesons are unstable and decay with a half-life of 18 ns.

It is found in experiments that approximately 75% of the π mesons that pass the first detector decay before reaching the second detector.

Show how this provides evidence to support the theory of special relativity. In your answer compare the percentage expected by the laboratory observer with and without application of the theory of special relativity.

(5)
(Total 8 marks)

Q3.(a) One of the two postulates of Einstein's theory of special relativity is that physical laws have the same form in all inertial frames of reference. Explain in terms of velocity what is meant by an inertial frame of reference.

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(1)

(b) Light takes 4.3 years to reach the Earth from the star Alpha Centauri.

(i) A space probe is to be sent from the Earth to the star to arrive 5.0 years later, according to an observer on Earth.

Assuming the space probe's velocity is constant, calculate its speed in ms^{-1} on this journey.

speed .... ms^{-1}

(1)

(ii) Calculate the time taken for this journey in years registered by a clock in the space probe.

time taken .... years

(3)

(Total 5 marks)

Q4. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space, *c*, is invariant.

Explain what is meant by this statement.

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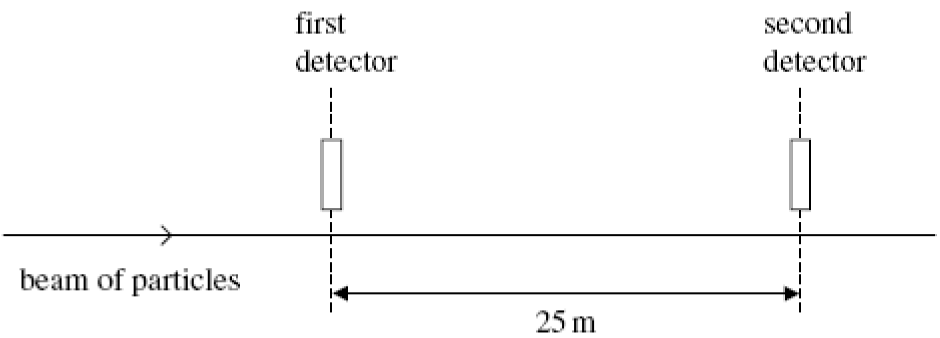
(1)

(b) A beam of identical particles moving at a speed of 0.98*c* is directed along a straight line between two detectors 25 m apart.



The particles are unstable and the intensity of the beam at the second detector is a quarter of the intensity at the first detector.

Calculate the half-life of the particles in their rest frame.

answer = ... s

(4)

(Total 5 marks)

Q5. (a) Calculate the speed at which a matter particle has a mass equal to 10 times its rest mass.

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(3)

(b) Explain why a matter particle can not travel as fast as a photon in free space even though its kinetic energy can be increased without limit.

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(3)
(Total 6 marks)