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.

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(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.(a) Calculate the speed of a particle at which its mass is twice its rest mass.

speed ..... m s^{-1}

(2)

(b) Use the axes below to show how the mass m of a particle changes from its rest mass m_o as its speed v increases from zero.

Mark and label on the graph the point **P** where the mass of the particle is twice its rest mass.

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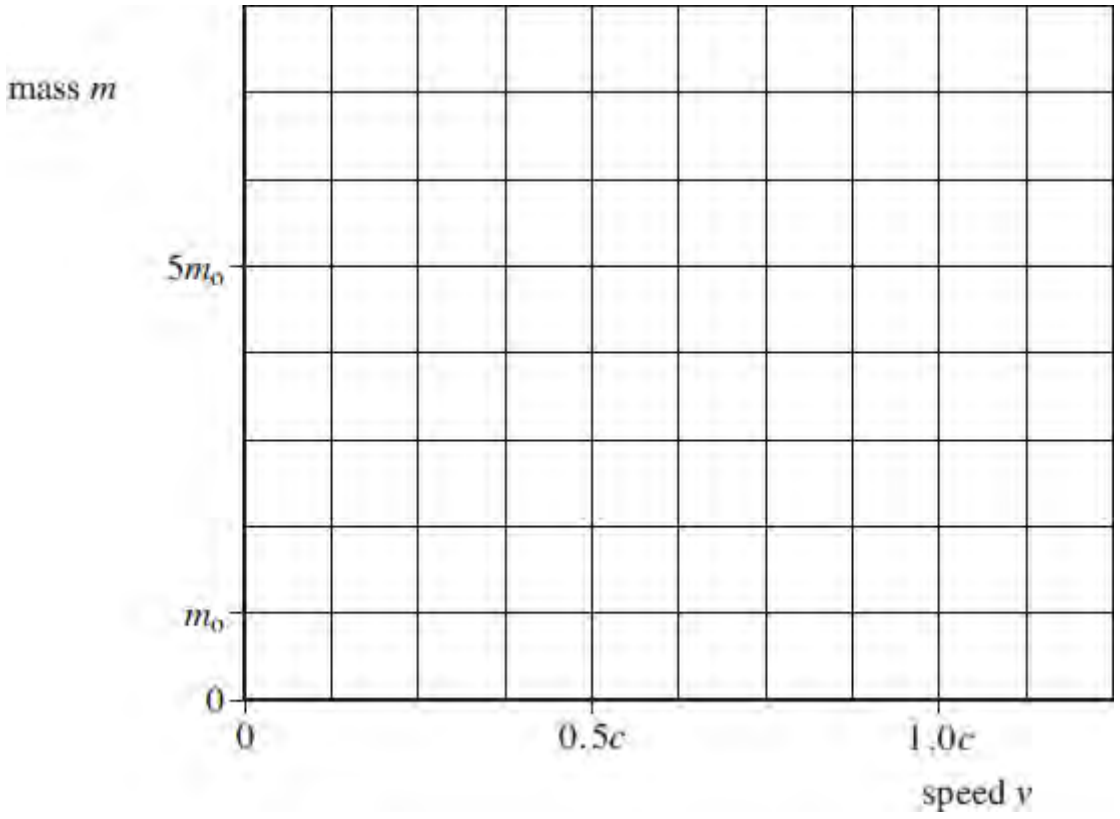

(3)

(c) By considering the relationship between the energy of a particle and its mass, explain why the theory of special relativity does not allow a matter particle to travel as fast as light.

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(2)
(Total 7 marks)

Q3. (i) Calculate the kinetic energy, in J, of a proton accelerated in a straight line from rest through a potential difference of 1.1×10^9 V.

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(ii) Show that the mass of a proton at this energy is 2.2 m_0, where m_0 is the proton rest mass.

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(iii) Hence calculate the speed of a proton of mass 2.2 m_0.

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(Total 7 marks)

Q4.(a) The speed of an object cannot be greater than or equal to the speed of light yet its kinetic energy can be increased without limit. Explain the apparent contradiction that the speed of an object is limited whereas its kinetic energy is not limited.

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(3)

(b) Protons are accelerated from rest through a potential difference of 2.1×10^{10} V.

(i) Show that the kinetic energy of a proton after it has been accelerated from rest through this potential difference is 3.4×10^{-9} J.

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(ii) Show that the mass of a proton with the kinetic energy value calculated in part (a) is approximately $23m_0$, where m_0 is its rest mass.

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(4)

(c) Calculate the speed of a proton which has a mass equal to $23m_0$.

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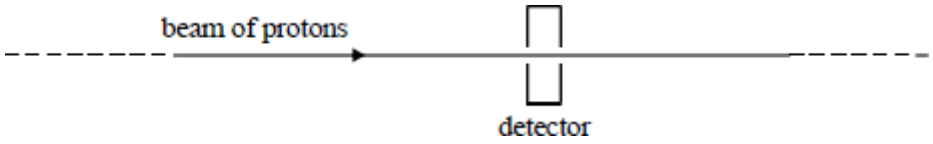
(3)
(Total 10 marks)

Q5. In a particle beam experiment, a pulsed beam of protons at a speed of 1.00×10^8 m s^{-1} passed through a stationary detector in a time of 15.0 ns.



(a) Calculate the length of the pulsed beam in

(i) the frame of reference of the detector,

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(ii) the frame of reference of the protons.

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(3)

(b) (i) Calculate the kinetic energy of each proton in the beam, in J.

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(ii) The beam consisted of 10^7 protons. It passed through the detector and was stopped by a stationary target. Calculate the average power which the proton beam delivered to the target during the pulse.

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(5)
(Total 8 marks)

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