

**1**

- (a) The theory of special relativity is based on two postulates. One of these postulates is that the speed of light in free space is invariant. State the other postulate.

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**(1)**

- (b) An electron in the Stanford linear accelerator is accelerated to an energy of 24.0 GeV.

- (i) An electron travelling with this energy has a velocity  $v$ .

Show that the value of  $\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$  is about  $2.1 \times 10^{-5}$ .

**(3)**

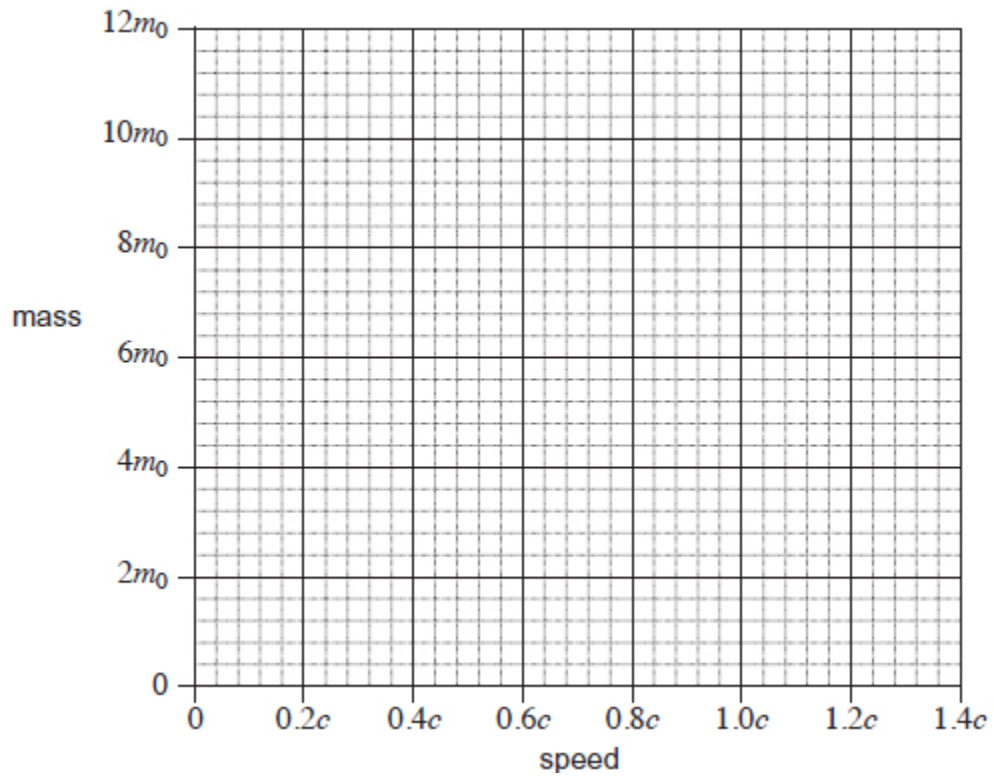
- (ii) The Stanford linear accelerator has a length of 3.0 km. Assume that the electron travels for the full length of the accelerator with an energy of 24 GeV. Calculate the length, in m, of the accelerator in the reference frame of the electron.

length of accelerator = ..... m

**(1)**

- (c) Draw a graph to show how the relativistic mass of an electron varies with speed as it is accelerated from rest.

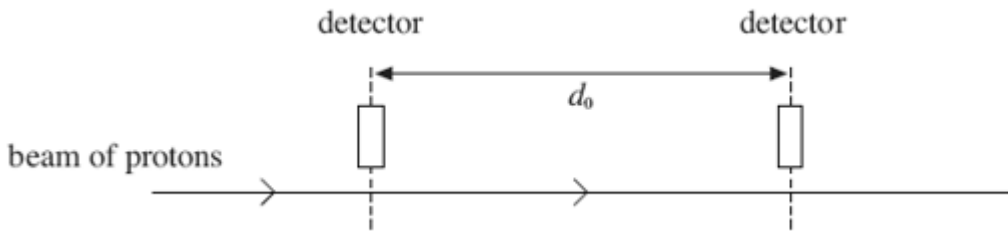
Rest mass of an electron =  $m_0$



(2)  
(Total 7 marks)

2

In an experiment, a beam of protons moving along a straight line at a constant speed of  $1.8 \times 10^8 \text{ms}^{-1}$  took 95 ns to travel between two detectors at a fixed distance  $d_0$  apart, as shown in the figure below.



- (a) (i) Calculate the distance  $d_0$  between the two detectors in the frame of reference of the detectors.

answer = ..... m

(1)

- (ii) Calculate the distance between the two detectors in the frame of reference of the protons.

answer = ..... m

(2)

- (b) A proton is moving at a speed of  $1.8 \times 10^8 \text{ms}^{-1}$

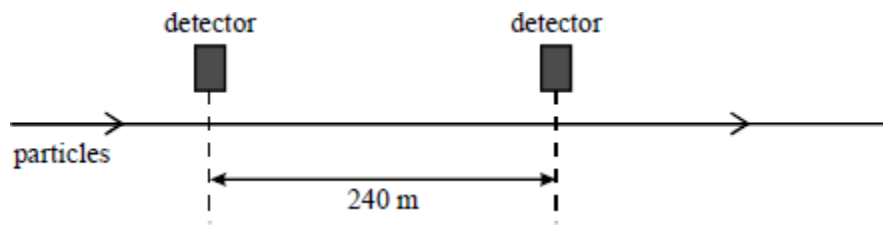
Calculate the ratio  $\frac{\text{kinetic energy of the proton}}{\text{rest energy of the proton}}$

answer = .....

(5)  
(Total 8 marks)

3

- (a) In a particle beam experiment, a short pulse of 1 ns duration of particles moving at constant speed passed directly between 2 detectors at a fixed distance apart of 240 m. The pulse took  $0.84 \mu\text{s}$  to travel from one detector to the other.



- (i) Calculate the speed of the particles.

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- (ii) Calculate the distance between the two detectors in the frame of reference of the particles.

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(4)

- (b) In a 'thought experiment' about relativity, a student stated that a twin who travelled from the Earth to a distant planet and back at a speed close to the speed of light would be the same age on return as the twin who stayed on Earth. Explain why this statement is **not** correct.

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(4)

(Total 8 marks)

4

In a particle beam experiment, a pulsed beam of protons at a speed of  $1.00 \times 10^8 \text{ m s}^{-1}$  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)

5

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

(i) Explain what is meant by this postulate.

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(ii) State and explain the other postulate.

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(4)

(b) A stationary muon has a rest mass of  $1.88 \times 10^{-28}$  kg and a half-life of  $2.2 \times 10^{-6}$  s.

Calculate

(i) the mass of a muon travelling at  $0.996 c$ , where  $c$  is the speed of light in a vacuum,

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- (ii) the distance, in a laboratory frame of reference, travelled in one half-life by a muon moving at  $0.996 c$ .

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**(6)**  
**(Total 10 marks)**