1)

(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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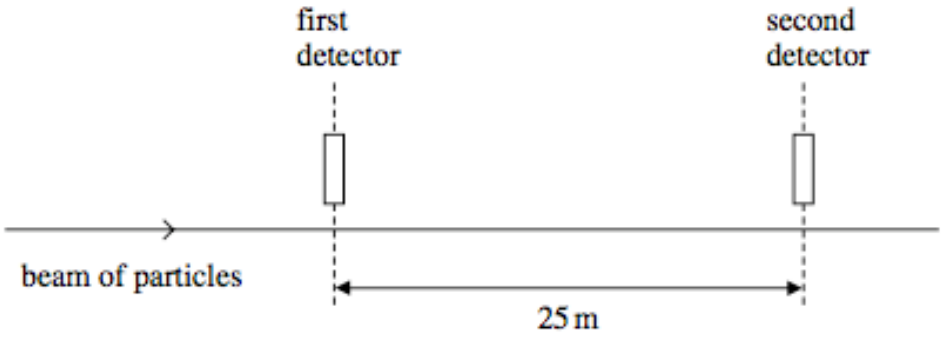
(1 mark)

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

Figure 5



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

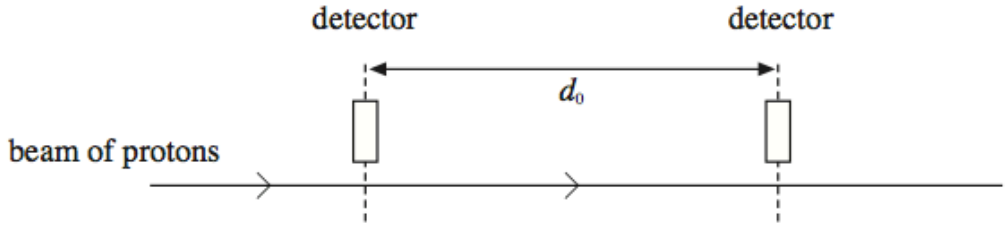
(4 marks)

END OF QUESTIONS

2)

In an experiment, a beam of protons moving along a straight line at a constant speed of $1.8 \times 10^8\,\text{m s}^{-1}$ took 95 ns to travel between two detectors at a fixed distance d_0 apart. As shown in **Figure 5**.

Figure 5



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

answer = ... m

(1 mark)

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

answer = ... m

(2 marks)

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

Calculate the ratio

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

answer = ...

(5 marks)

3)

(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.

[1 mark]

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

(b) (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 $\mathrm{m\,s^{-1}}$ on this journey.

[1 mark]

speed ..... $\mathrm{m\,s^{-1}}$

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

[3 marks]

time taken ..... years

4)

A muon is an unstable particle produced by cosmic rays in the Earth's atmosphere. Muons that are produced at a height of $10.7\ \text{km}$ 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 $1.60 \times 10^{-6}\ \text{s}$.

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

[3 marks]

number of muons .....

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

[1 mark]

	✓ 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	

(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 marks]

(b) (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 $0.98c$.

[1 mark]

potential difference = ... V

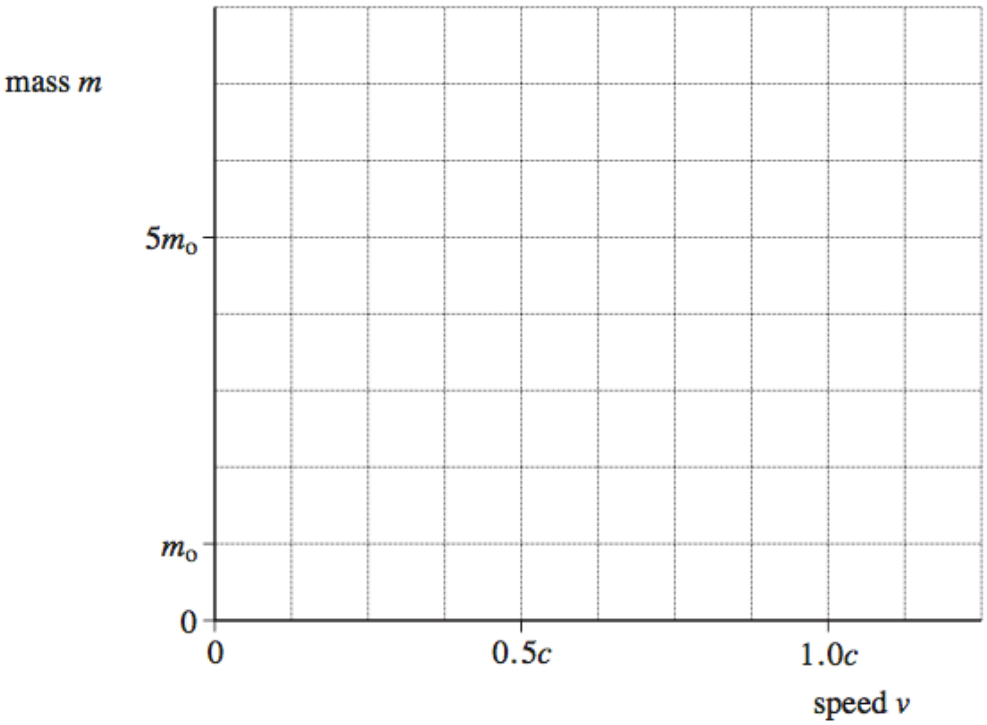
5)

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

speed ..... $m\,s^{-1}$

(2 marks)

(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.



(3 marks)

(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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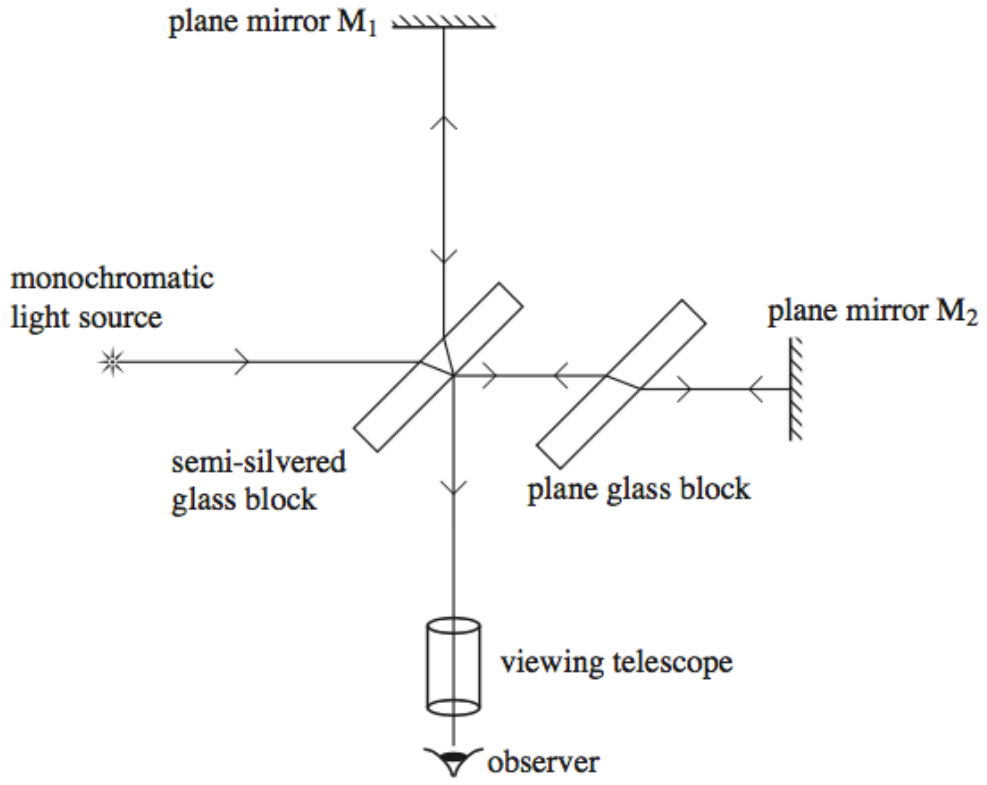
(2 marks)

6)

Figure 3 represents the Michelson-Morley interferometer. Interference fringes are seen by an observer looking through the viewing telescope.

Figure 3



(a) Explain why the interference fringes shift their position if the distance from either of the two mirrors to the semi-silvered block is changed.

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(2 marks)

(b) Michelson and Morley predicted that the interference fringes would shift when the apparatus was rotated through 90°. When they tested their prediction, no such fringe shift was observed.

(b) (i) Why was it predicted that a shift of the fringes would be observed?

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(3 marks)

(b) (ii) What conclusion was drawn from the observation that the fringes did not shift?

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(1 mark)