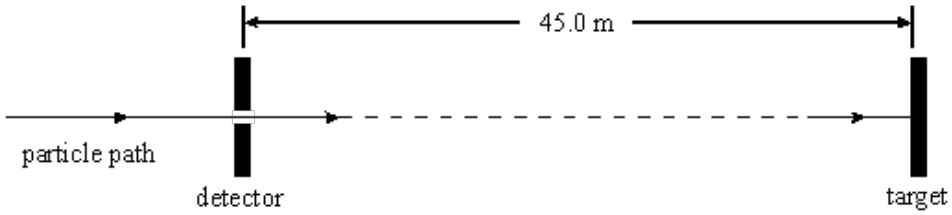
Q1. A particle passes through a detector and 152 ns later hits a target 45.0 m away from the detector.



(i) Calculate the speed of the particle between the detector and the target.

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(ii) Calculate the transit time of the particle from the detector to the target, in the frame of reference of the particle.

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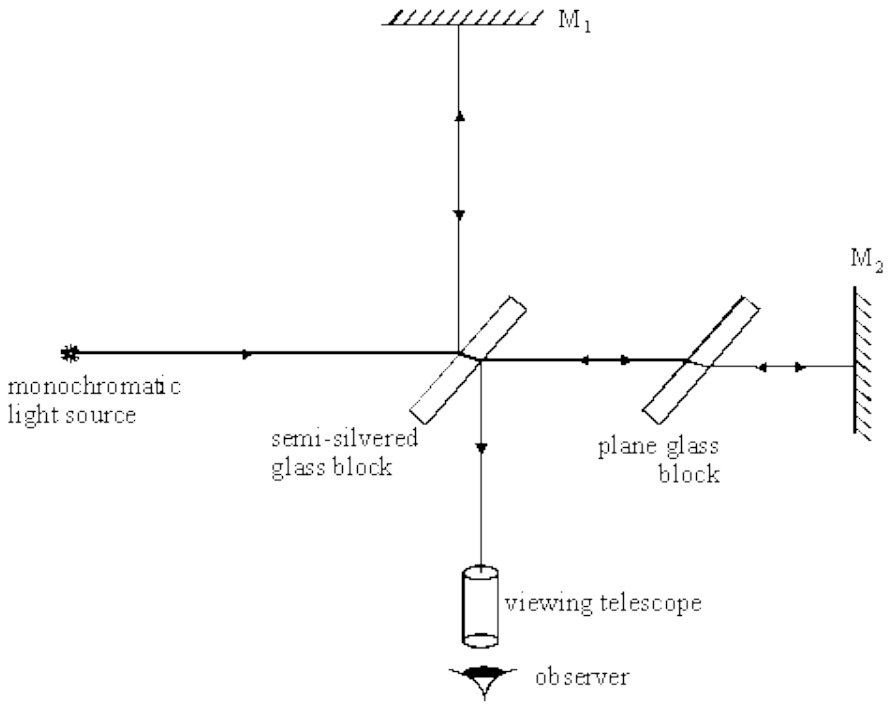
(Total 4 marks)

Q2. The Michelson-Morley experiment represented in the diagram was designed to find out if the speed of light depended on its direction relative to the Earth's motion through space. Interference fringes were seen by the observer.



(a) (i) Explain why interference fringes were seen.

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(ii) The interference fringe pattern did not shift when the apparatus was rotated by 90°. Explain the significance of this null observation.

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(5)

(b) Einstein postulated that the speed of light in free space is invariant. Explain what is meant by this postulate.

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(2)
(Total 7 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, with the aid of a suitable example, what is meant by an inertial frame of reference.

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(2)

(b) A certain type of sub-atomic particle has a half-life of 18 ns when at rest. A beam of these particles travelling at a speed of 0.995*c* is produced in an accelerator.

(i) Calculate the half-life of these particles in the laboratory frame of reference.

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(ii) Calculate the time taken by these particles to travel a distance of 108 m in the laboratory at a speed of 0.995*c* and hence show that the intensity of the beam is reduced to 25% of its original value over this distance.

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(5)
(Total 7 marks)

Q4. (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)

Q5. (a) In a science fiction film, a space rocket travels away from the Earth at a speed of 0.994 *c*, where *c* is the speed of light in free space. A radio message of duration 800 s is transmitted by the space rocket.

(i) Calculate the duration of the message when it is received at the Earth.

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(ii) Calculate the distance moved by the rocket in the Earth's frame of reference in the time taken to send the message.

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(4)

(b) A student claims that a twin who travels at a speed close to the speed of light from Earth to a distant star and back would, on return to Earth, be a different age to the twin who stayed on Earth. Discuss whether or not this claim is correct.

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(3)
(Total 7 marks)

Q6. (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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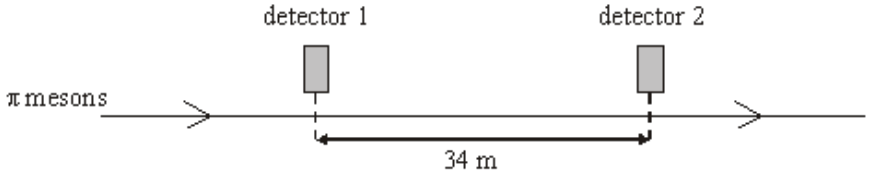
(3)
(Total 6 marks)

Q7. π mesons, travelling in a straight line at a speed of 0.95 *c*, pass two detectors 34 m apart, as shown in the figure below.



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

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(ii) π mesons are unstable and decay with a half-life of 18 ns when at rest. Show that approximately 75% of the π mesons passing the first detector decay before they reach the second detector.

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(Total 5 marks)

Q8. (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 1.9×10^{-28} kg.

For a muon travelling at a speed of 0.995 *c*, where *c* is the speed of light in a vacuum, calculate

(i) its mass,

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(ii) its total energy, in J.

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(iii) its kinetic energy, in J.

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(6)
(Total 10 marks)

Q9. (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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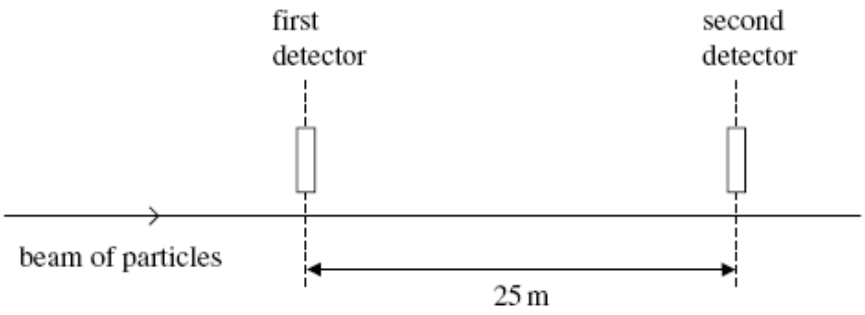
(1)

(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.

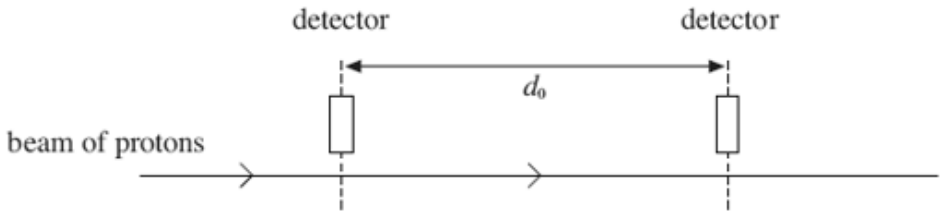
Calculate the half-life of the particles in their rest frame.

answer = ... s

(4)

(Total 5 marks)

Q10. 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 $1.8 \times 10^{8} \text{ms}^{-1}$

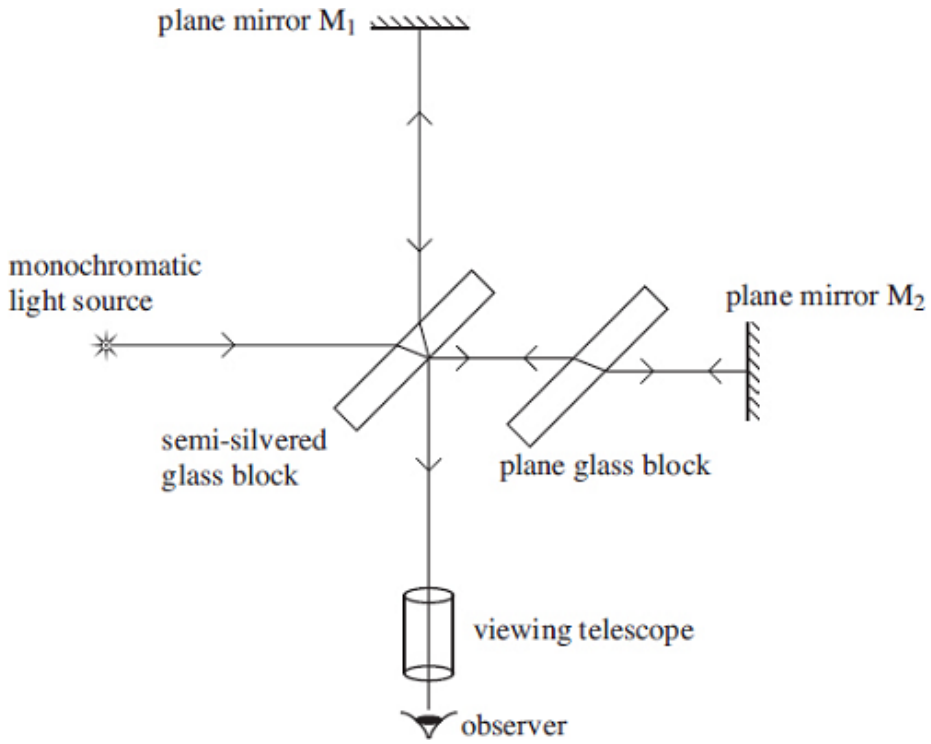
Calculate the ratio $\frac{\text{kinetic energy of the proton}}{\text{rest energy of the proton}}$

answer = ...

(5)

(Total 8 marks)

Q11. The figure below represents the Michelson-Morley interferometer. Interference fringes are seen by an observer looking through the viewing telescope.



(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)

(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.

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

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

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(1)

(Total 6 marks)

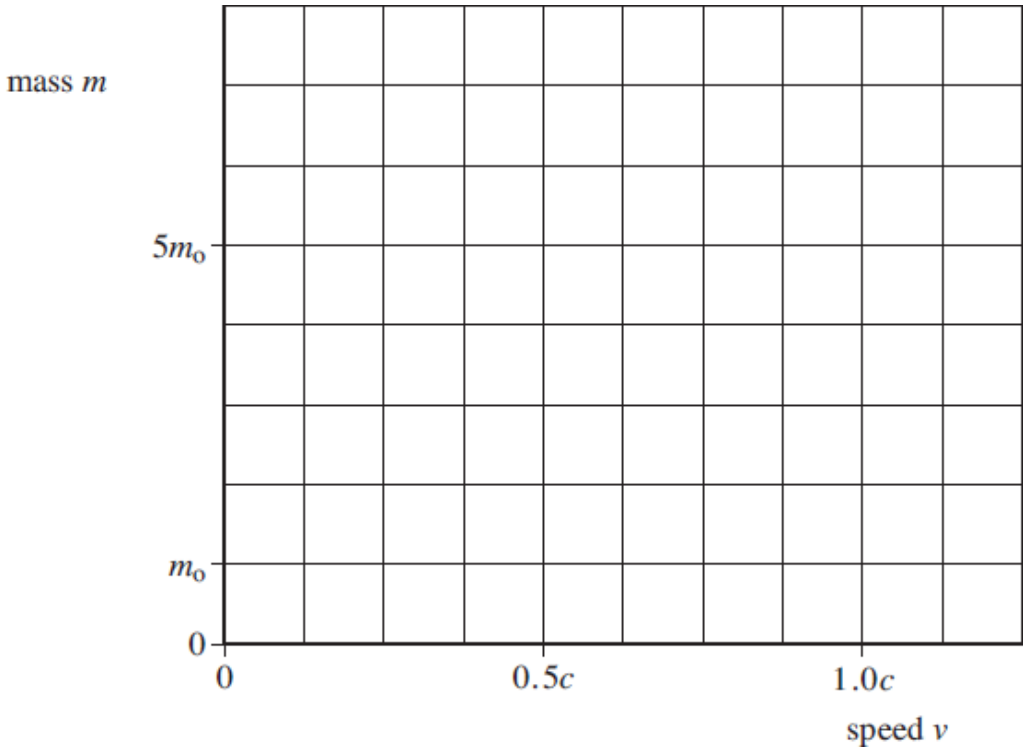
Q12. (a) Calculate the speed of a particle at which its mass is twice its rest mass.

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.



(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)