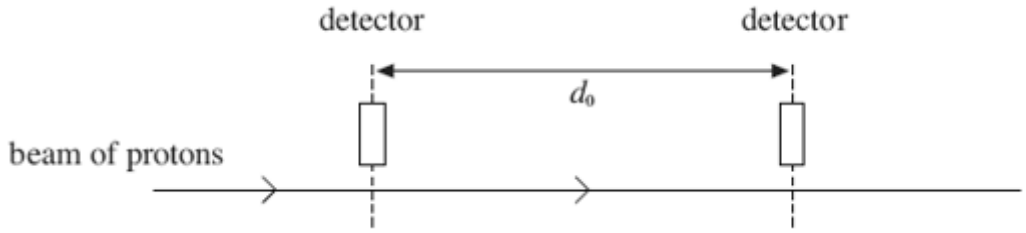
Q1. In an experiment, a beam of protons moving along a straight line at a constant speed of $1.8 \times 10^8 \text{ms}^{-1}$ took 95 ns to travel between two detectors at a fixed distance d_0 apart, as shown in the figure below.



(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)

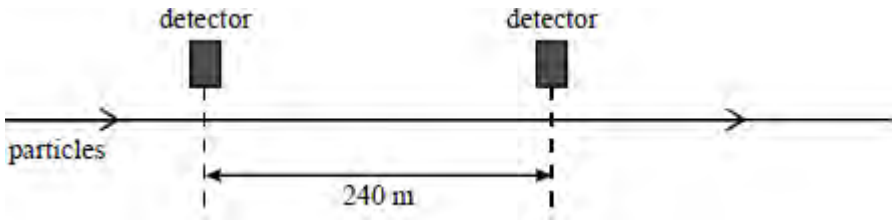
(b) A proton is moving at a speed of $1.8 \times 10^8 \text{ms}^{-1}$

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

answer = ...

(5)
(Total 8 marks)

Q2.(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 μs 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)

Q3.(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 1.88×10^{-28} kg and a half-life of 2.2×10^{-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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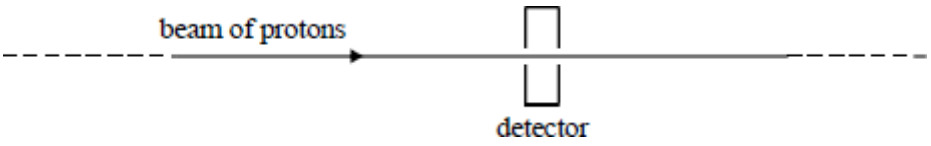
(6)
(Total 10 marks)

Q4. 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)