A-Level Physics

Time Dilation

Question Paper

Time available: 42 minutes
Marks available: 31 marks

1. (a) A student models a spacecraft journey that takes one year. The spacecraft travels directly away from an observer at a speed of 1.2×10^7 m s^{-1}. The student predicts that a clock stationary relative to the observer will record a time several days **longer** than an identical clock on the spacecraft.

Comment on the student's prediction. Support your answer with a time dilation calculation.

(4)

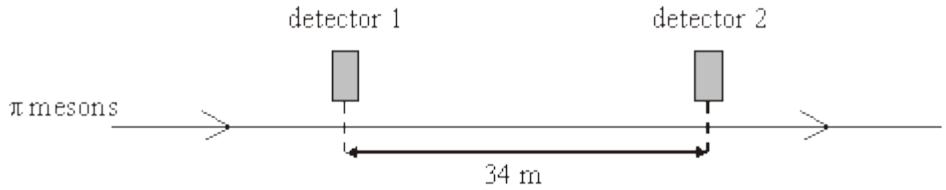
(b) In practice, the gravitational field of the Sun affects the motion of the spacecraft and it does not travel directly away from the Earth throughout the journey.

Explain why this means that the theory of special relativity cannot be applied to the journey.

(2)

(Total 6 marks)

2. 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.

(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.

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

(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.

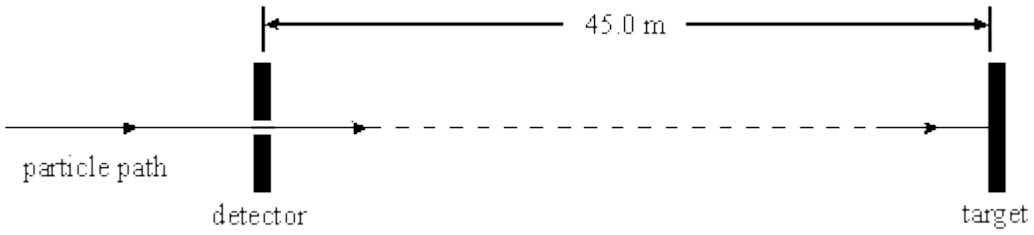
(i) Calculate the half-life of these particles in the laboratory frame of reference.

(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.

(5)

(Total 7 marks)

4. 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.

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

(Total 4 marks)

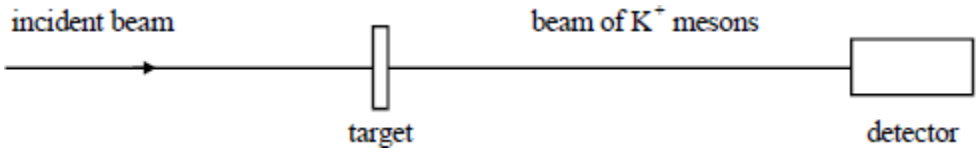
5. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(i) Explain what is meant by this statement.

(ii) What is the other postulate?

(3)

(b) K^+ mesons are sub-atomic particles of half-life 86 ns when at rest. In an accelerator experiment, a beam of K^+ mesons travelling at a speed of $0.95c$ is created, where c is the speed of light.



(i) Calculate the half-life of the K^+ mesons in the beam measured in the laboratory frame of reference.

(ii) What is the greatest distance that a detector could be sited from the point of production of the K^+ mesons to detect at least 25% of the K^+ mesons produced?

(6)

(Total 9 marks)