InkPhysics

QUESTION WORKBOOK

The consequences of special relativity

Turning points · Year 13

AQA 3.12.3.3, 3.12.3.4, 3.12.3.5

18 questions · 53 marks

NAVY SCREEN EDITION

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SECTION A · Warm-up

A1 Define the proper time between two events. [2]

A2 Define the proper length of an object. [2]

A3 Using the idea of relativistic mass, explain why no object can be accelerated to the speed of light. [2]

A4 State what is meant by the rest energy of a particle. [1]

A5 Calculate the rest energy of a proton. Mass of a proton = 1.67×10^{-27} kg; c = 3.00×10^{8} m s^{-1}. [2]

SECTION B · Standard

B1 A muon's lifetime in its rest frame is 2.2 μs. Calculate its lifetime as measured in a laboratory it passes at 0.95c. [3]

B2 A spacecraft of proper length 120 m passes Earth at 0.60c. Calculate its length as measured from Earth. [3]

B3 Explain how the arrival of cosmic-ray muons at the Earth's surface provides evidence for time dilation. [4]

B4 An electron (rest energy 8.2×10^{-14} J) travels at 0.98c. Calculate its total energy. [3]

B5 A beam of pions has a rest-frame lifetime of 26 ns. In the laboratory their lifetime is measured as 52 ns. Determine the speed of the pions. $c = 3.00 \times 10^{8}$ m s^{-1}. [3]

B6 A muon created 10 km above the ground travels straight down at 0.996c. Calculate the thickness of the atmosphere below it as measured in the muon's rest frame, and state which frame measures the proper 10 km. [3]

B7 An accelerator gives an electron a total energy of 4.1×10^{-13} J. The electron's rest energy is 8.2×10^{-14} J. Determine the electron's speed. $c = 3.00 \times 10^{8}$ m s^{-1}. [4]

SECTION C · Stretch

C1 A spacecraft passes Earth at 0.80c. Its on-board clock records 60 s between two signals, and its proper length is 90 m. Calculate the time between the signals and the craft's length as measured from Earth. [4]

C2 Describe Bertozzi's experiment and explain what it demonstrated directly. [4]

C3 Describe the shape of a graph of an object's mass against its speed, from rest towards the speed of light. [2]

C4 The crew of a spacecraft travelling at 0.70c set off for a star 4.2 light years away, as measured from Earth. The mission plan requires the crew to age less than 4.5 years during the journey. Deduce whether the plan is met. (A light year is the distance light travels in one year; its value in metres is not needed.) [5]

C5 Show that classical physics predicts an impossible speed for electrons accelerated from rest through 4.5 MV, and state what Bertozzi's measurements showed such electrons actually do. $e/m = 1.76 \times 10^{11}$ C kg^{-1}; $c = 3.00 \times 10^{8}$ m s^{-1}. [3]

C6 A student sketches the kinetic energy of an electron against its speed as the classical curve $E_k = \frac{1}{2}m_0v^2$. Describe how the correct relativistic curve differs.

[3]