2021 Ph H2 Q7

Section: Particles and Waves

Topic: Accelerators, Relativity, Mesons, Higgs Boson

Linac4 at CERN accelerates hydrogen ions before they enter the LHC. (a)(i) Explain use of alternating voltage, (ii) explain tube lengths increasing. (b) Length contraction of 13 m tube at 0.50c. (c)(i) Define meson, (ii) deduce direction of magnetic field for π^- meson. (d)(i) Name weak force mediator, (ii) calculate mass of bottom quark from 4.20 GeV.

Worked solution

(a)(i) An alternating supply voltage ensures that each time the ions reach a gap, the polarity of the electric field is such that they are accelerated forward. With a constant supply, ions would eventually be decelerated in alternate gaps.

(a)(ii) As ions gain speed, they take less time to cross each tube. To keep them in step with the changing polarity, the tube length must increase so transit time matches the half-cycle of the alternating voltage.

(b) Length contraction formula: $L' = L\sqrt{(1 - v^2/c^2)}$
$= 13.0 \times \sqrt{(1 - 0.50^2)}$
$= 11.26$ m

Answer: 11.3 m

(c)(i) A meson is a hadron consisting of a quark and an antiquark.

(c)(ii) The π^- meson is negatively charged. Using Fleming's left hand rule, its curved path indicates the magnetic field is out of the page.

(d)(i) Weak force mediators: W^+, W^-, or Z^0 bosons.

(d)(ii) Mass-energy equivalence: $E = mc^2$
$E = 4.20\ \text{GeV} = 4.20\times10^9 \times 1.60\times10^{-19} = 6.72\text{e-}10\ \text{J}$
$m = E/c^2 = 6.72\text{e-}10/(3.0\times10^8)^2 = 7.47\text{e-}27\ \text{kg}$

Answer: 7.5×10^{-27} kg

Final answers

(a)(i) Alternating voltage ensures continuous acceleration

(a)(ii) Tube length increases to stay in phase with ions

(b) L' ≈ 11.3 m

(c)(i) Meson = quark + antiquark

(c)(ii) Field direction = out of page

(d)(i) Mediators: W^+, W^-, Z^0

(d)(ii) m ≈ 7.5×10^{-27} kg

Revision tips

- Linacs need alternating voltage to keep acceleration consistent.
- Tube lengthening matches ion speed increases with AC cycle timing.
- Relativistic length contraction: $L' = L\sqrt{(1 - v^2/c^2)}$.
- Mesons are quark–antiquark pairs; baryons are 3 quarks.
- Weak interaction mediated by W and Z bosons.