2019 Ph H2 Q7

Section: Particles and Waves

Topic: Standard Model, Pentaquarks, Relativity, $E=mc^2$

The question introduces a newly discovered pentaquark (Λb), made of 5 quarks: 2 up, 1 down, 1 charm, 1 anticharm. (a) Define fundamental particle and name group containing quarks & leptons. (b) Calculate charge of the pentaquark. (c) Quark-antiquark pair: name the type of particle, then calculate time-dilated lifetime at 0.91c. (d) Convert mass-energy 4450 MeV into joules and then into mass.

Worked solution

(a)(i) A fundamental particle is one that cannot be broken down into anything smaller. Quarks and leptons are considered fundamental.

(a)(ii) Quarks and leptons are members of the group of fermions, the matter particles in the Standard Model.

(b) Total charge of Λb pentaquark:
Quarks: 2 up (+2/3 each), 1 down (−1/3), 1 charm (+2/3), 1 anticharm (−2/3).
Total = 2(+2/3) + (−1/3) + (+2/3) + (−2/3) = +1.

Answer: +1e

(c)(i) A quark–antiquark pair forms a meson.

(c)(ii) Proper lifetime $\tau_0 = 8.0\times10^{-21}$ s.
Moving at 0.91c, time dilation factor $\gamma = 1/\sqrt{(1 - v^2/c^2)}$.
$\gamma = 2.41$.
$\tau = \gamma \tau_0 = 2.41 \times 8.0\times10^{-21} = 1.93\text{e-}20$ s.

Answer: 1.8×10^{-20} s

(d)(i) Energy from mass–energy equivalence:
$E = 4450$ MeV $= 4450\times10^6$ eV.
1 eV $= 1.60\times10^{-19}$ J.
$E = 7.12\text{e-}10$ J.

Answer: 7.12×10^{-10} J

(d)(ii) Mass $m = E/c^2 = (7.12\times10^{-10})/(3.0\times10^8)^2$.
$= 7.91\text{e-}27$ kg.

Answer: 7.9×10^{-27} kg

Final answers

(a)(i) Fundamental: indivisible
(a)(ii) Group: Fermions
(b) Charge = +1e
(c)(i) Meson
(c)(ii) Lifetime = 1.8×10^{-20} s
(d)(i) Energy = 7.1×10^{-10} J
(d)(ii) Mass = 7.9×10^{-27} kg

Revision tips

- Fundamental particles are indivisible — quarks & leptons.

- Quarks + leptons belong to fermions (matter particles).

- Mesons = quark + antiquark; baryons = 3 quarks.

- Use $\gamma = 1/\sqrt{1 - v^2/c^2}$ for time dilation.

- E (J) = energy (MeV) × 1.6×10^{-13}; mass from $m = E/c^2$.