2017 H2 Q7

Section: Particles and Waves

Topic: Standard Model • Baryons (Σ) • Strong force • Time dilation

(a) Why protons and neutrons are not fundamental

They are composite particles (baryons) made of three quarks: proton = uud, neutron = udd. Fundamental particles have no substructure.

(b) Sigma (Σ) baryons — quark content and charge

Using the data-book information for the Σ family (three-quark baryons including a strange quark):

Particle	Symbol	Typical quark content	Charge
Sigma plus	Σ■	u u s	+1 e
Sigma zero	Σ■	u d s	0
Sigma minus	Σ■	d d s	–1 e

Charges follow from quark charges (u = +2/3 e, d = −1/3 e, s = −1/3 e).

(c) Binding force and its boson

(i) The quarks in a Σ baryon are held together by the strong (colour) force.

(ii) The exchange boson is the gluon.

(d) Time dilation for Σ^- at 0.9 c

Proper (rest-frame) mean lifetime: $\tau = 1.5 \times 10^{-10}$ s.

Time dilation: $t = \gamma \tau$ with $\gamma = 1 / \sqrt{(1 - v^2/c^2)}$.

$\gamma = 1 / \sqrt{(1 - 0.9^2)} = 2.294$.

Observed lifetime $t = \gamma \tau = 2.294 \times 1.5 \times 10^{-10}$ s = 3.44e-10 s.

Answer: ≈ 3.4×10^{-10} s.

Revision tips

- Baryons are made of three quarks; mesons are quark–antiquark pairs; leptons are fundamental.
- Strong force confines quarks; gluons carry colour charge.
- Relativistic lifetimes: multiply rest lifetime by $\gamma = 1/\sqrt{(1 - v^2/c^2)}$.