

Particle Physics: Problem Sheet 1

The Standard Model and Practical Particle Physics

1. List all fundamental fermions in the Standard Model.
2. What quantum numbers are associated with leptons? Are they conserved in strong, weak and electromagnetic interactions?
3. What quantum numbers are associated with quarks? Are they conserved in strong, weak and electromagnetic interactions?
4. What are the charge and quark flavour quantum numbers for the \bar{u} , \bar{d} and \bar{s} quarks? What are the quantum numbers of the lambda anti-baryon, $\bar{\Lambda}^0$, and of the antiproton, \bar{p} ?
5. Use the Pauli exclusion principle to argue why in the Δ^{++} baryon (which has total spin, $S = 3/2\hbar$ and consists of three up quarks) all the quarks have a different colour charge.
6. Explain why the decays $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$ and $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ are allowed and why $\mu^+ \rightarrow e^+ \gamma$ and $\mu^+ \rightarrow e^+ e^- e^+$ are forbidden. What about $\mu^+ \rightarrow e^- \bar{\nu}_e \nu_\mu$?
7. What is 1 fm in inverse GeV? How many seconds is 1 inverse GeV?
8. Write down the typical lifetimes for particles that decay by:
 - (a) The strong force
 - (b) The electromagnetic force
 - (c) The weak force

By looking at the lifetimes on the Particle Properties sheet, which force is responsible for the decay of π^0 , B^+ , ω^0 ?

9. The lifetime of the η^0 has not been measured directly. The total width of the η^0 has been measured to be $\Gamma(\eta^0) = 0.203 \pm 0.016$ MeV. What is the lifetime of the η^0 ? What force is responsible for its decay?
10. What are the centre-of-mass energies, E_{CM} , of the following machines:
 - LEP1: e^+e^- collider, both beams 45.6 GeV
 - LHC: pp collider, both beams 7 TeV
 - HERA: ep collider, $E_e = 30$ GeV and $E_p = 820$ GeV.

If HERA were a fixed target machine what energy would the electron require to give an equivalent CM energy?

11. The Δ^{++} baryon can be produced by aiming a pion beam onto a hydrogen target to produce the reaction $\pi^+ p \rightarrow \Delta^{++} \rightarrow \pi^+ p$. Calculate the energy and momentum of the pions in the Δ^{++} centre-of-mass frame.

From the measured total width $\Gamma(\Delta) = 120$ MeV calculate the lifetime of the Δ^{++} .

12. The B_d meson has a mass of 5.28 GeV/ c^2 and mean lifetime of 1.54 ps. At LEP B_d mesons were produced with an average energy of 32 GeV. Calculate the mean decay length of a B_d meson at LEP.
13. The cross section to make b-quarks at LEP with $E_{\text{CM}} = 91.2$ GeV was $\sigma(e^+e^- \rightarrow b\bar{b}) = 4.5$ nb. How many $e^+e^- \rightarrow b\bar{b}$ events were produced at LEP with a integrated luminosity of $\int \mathcal{L} dt = 100$ pb $^{-1}$?