

Particle Physics: Problem Sheet 1

The Standard Model, Practical Particle Physics and QED

1. List all fundamental fermions in the Standard Model.
2. 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 $\mu^+ \rightarrow e^- \bar{\nu}_e \nu_\mu$?
3. What is 1 fm in inverse GeV? How many seconds is 1 inverse GeV?
4. 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 ?

5. 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?
6. 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?

7. 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^{++} .

8. The B_d meson has a mass of $5.28 \text{ GeV}/c^2$ 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.
9. 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 $\int \mathcal{L} dt = 100 \text{ pb}^{-1}$?
10. The simplest vertex in QED is a fermion-fermion-photon vertex. Draw an example Feynman diagram for such a vertex. Write down *all* possible electromagnetic fermion-fermion-photon vertices.
11. Draw the lowest order Feynman diagram for electron-proton scattering $e^- p \rightarrow e^- p$. Discuss the corresponding scattering amplitude or Matrix element, $\mathcal{M}$.

Show that the photon propagator is the origin of the $1/\sin^4(\frac{\theta}{2})$ dependence of the Rutherford cross section for $e^- p \rightarrow e^- p$ scattering.