# Particle Physics: Problem Sheet 1

## The Standard Model and Practical Particle Physics

1. List all fundamental fermions in the Standard Model.

2. Explain why the decays $\mu^- \to e^- \bar{\nu}_e \nu_\mu$ and $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ are allowed and why $\mu^+ \to e^+ \gamma$ and $\mu^+ \to e^+ e^- e^+$ are forbidden. What about $\mu^+ \to e^- \bar{\nu}_e \nu_\mu$?

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 liftetimes on the Particle Properties sheet, which force is responsible for the decay of $\pi^0$, $B^+$, $\omega^0$?

5. The lifetime of the $\eta'^0$ has not been measured directly. The total width of the $\eta'^0$ has been measured to be $\Gamma(\eta'^0) = 0.203 \pm 0.016$ MeV. What is the lifetime of the $\eta'^0$? What force is responsible for its decay?

6. What are the centre-of-mass energies, $E_{\rm CM}$, of the following machines:

   - LEP1: $e^+e^-$ collider, both beams 45.6 GeV
   - LHC: $pp$ collider, both beams 7 TeV
   - HERA: $ep$ collider, $E_{\rm e} = 30$ GeV and $E_{\rm p} = 820$ GeV.

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

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

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

8. 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.

9. The cross section to make b-quarks at LEP with $E_{\rm CM} = 91.2$ GeV was $\sigma(e^+e^- \to {\rm b\bar{b}}) = 4.5$ nb. How many $e^+e^- \to {\rm b\bar{b}}$ events were produced at LEP with a integrated luminosity of $\int \mathcal{L} dt = 100$ pb$^{-1}$?