PHYS3002 - NUCLEI AND PARTICLES

Problem Sheet 4 - Due March 20, 2015

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\begin{aligned}
m_p &= 938\,\mathrm{MeV/c^2} \\
m_n &= 940\,\mathrm{MeV/c^2} \\
m_\Sigma &= 1189\,\mathrm{MeV/c^2} \\
m_\Omega &= 1672\,\mathrm{MeV/c^2} \\
m_\pi &= 135\,\mathrm{MeV/c^2} \\
m_K &= 495\,\mathrm{MeV/c^2} \\
m_{\Xi^*} &= 1530\,\mathrm{MeV/c^2}
\end{aligned}
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1. At the possible future electron-proton collider eLHC 7 TeV protons will be scattered against electrons with energy of 67 GeV. What is the centre-of-mass energy of the proton-electron system. [3]

   [Note: Protons and electrons with energies are both extremely relativistic so that their masses can be neglected when determining their momenta.]

2. The cross-section for the production of the expected Higgs boson at the forthcoming LHC is predicted to be 10 fb (femto=10^{-15}). At the design luminosity of 10^{34} /cm^2/sec., how accurately will one be able to determine this cross-section after one day of running? [2]

3. Several Σ^+ particles are produced, each with a (total) energy of 10 GeV. The mass of the Σ^+ is $1.189\,\mathrm{GeV/c^2}$ and its lifetime (at rest) is 8×10^{-11} secs. On average how long are the tracks left in a detector by these particles? Why would you not expect all the tracks to be of the same length, despite the fact that they all have the same energy? [3]

4. The J/ψ meson (which is a bound state of a c-quark and $\bar{c}$ anti-quark) has a lifetime of 7.6×10^{-21} secs. The partial width for its decay into an electron-positron pair is 5.3 KeV. What is the branching ratio for decay of the J/ψ into an electron-positron pair? [3]

5. The total width of W-boson decay is 2.1 GeV, the ratio of its partical decay width to leptons to its partial decay width to hadrons is 0.5. Assuming that W-decay branching fraction to any quark flavor is the same, calculate the partial W-boson decay width to $u\bar{d}$ quark pair. [2]

6. In the original Yukawa theory of strong interactions, these interactions were mediated by the exchange of virtual pions (mass $135\,\mathrm{MeV/c^2}$). What is the range of such interactions? [2]

7. The neutral meson $\overline{B^0}$ (flavour B=-1) and the charged meson, B^- contain a $b-$quark. They have zero strangeness or charm. What is the anti-quark to which the b-quark is bound.

   The meson $\overline{B_s}$ also has a b-quark but has strangeness +1. What is the anti-quark to which it is bound. What is the electric charge of the $\overline{B_s}$. What is the quark and antiquakr content of the B_s meson (flavour B=+1)? What is its strangeness?

   What are the isospins of the B^0, B^- and B_s? [3]

8. Which of the following are allowed by strong interactions (state your reasons)

$$\begin{aligned} p + p &\rightarrow \Sigma^+ + K^+ + n \\ p + p &\rightarrow \Xi^0 + K^+ + p \\ K^- + p &\rightarrow K^0 + n \\ K^- + p &\rightarrow \overline{K^0} + n \\ K^+ + n &\rightarrow K^0 + p \\ \pi^+ + p &\rightarrow p + p \\ \pi^+ + p &\rightarrow p + p + \bar{n} \\ \pi^+ + p &\rightarrow \Xi^0 + K^+ + K^+ \\ \Xi^- &\rightarrow \Lambda + K^- \\ \Xi^0 &\rightarrow p + K^- \end{aligned}$$

   [3]

9. What is the ratio of the reaction cross sections

$$\sigma(n + n \rightarrow \pi^- + d)/\sigma(n + p \rightarrow \pi^0 + d)$$

   at the same center-of-mass energy? Use isospin consideration, d dnotes Deutron $|d\rangle = |0, 0\rangle$ for I, I_3 state. [4]

Non-Assessed Questions

1. Explain the working of a cyclotron. What modifications need to be made for particles which move with relativistic velocities and why are such modifications necessary?

2. Explain how a linear accelerator can accelerate both electrons and protons in the same beam-pipe.

3. What are the quark contents of the following baryons:

$$p,\ n,\ \Lambda,\ \Sigma^+,\ \Xi^-,\ \Omega^-, \Delta^{++}, \Delta^0,\ \Delta^-\ ?$$

   What are the quark contents of the following mesons:

$$\pi^+,\ \pi^-\ K^0,\ \overline{K^0},\ \rho^+,\ \rho^-, K^+,\ K^-\ ?$$

4. Explain why the concept of colour was introduced into the quark model. Use this to explain why the Ω^- (strangeness=-3) must have spin-$\frac{3}{2}$.