Travaux Dirigés de Physique des Particules

Particle physics: elementary constituents, interactions, Feynman diagrams, isospin

Quark content of some mesons [1] and baryons

$$\pi^{\mathrm{o}} = (u\bar{u} - d\bar{d})/\sqrt{2} \quad \pi^+ = u\bar{d} \quad \pi^- = \bar{u}d$$
$$K^{\mathrm{o}} = d\bar{s} \qquad\qquad K^+ = u\bar{s} \quad K^- = \bar{u}s$$
$$D^+ = c\bar{d} \qquad\qquad D^0 = c\bar{u}$$

$$p = uud \qquad\qquad n = udd$$
$$\Sigma^{\mathrm{o}} = sud \qquad\qquad \Sigma^+ = uus \quad \Sigma^- = dds$$
$$\Xi^{*+} = ssd \qquad\qquad \Lambda^{\mathrm{o}} = sud$$

Exercise #1:
Indicate the family of the neutrino or antineutrino for the following interactions

$$\pi^+ \longrightarrow \pi^{\mathrm{o}} + e^+ + \nu \qquad \mu^+ \longrightarrow e^+ + \nu + \nu$$
$$\mu^- \longrightarrow e^- + \nu + \nu \qquad \nu + p \longrightarrow n + e^+$$
$$\nu + p \longrightarrow \mu^- + p + \pi^+$$

Exercise #2:
Determine if the following reactions are allowed:

$$n \longrightarrow p + \gamma \qquad p \longrightarrow e^+ + \gamma$$
$$p \longrightarrow \pi^+ + \gamma \qquad \bar{p} + n \longrightarrow \pi^- + \pi^{\mathrm{o}}$$

Exercise #3:
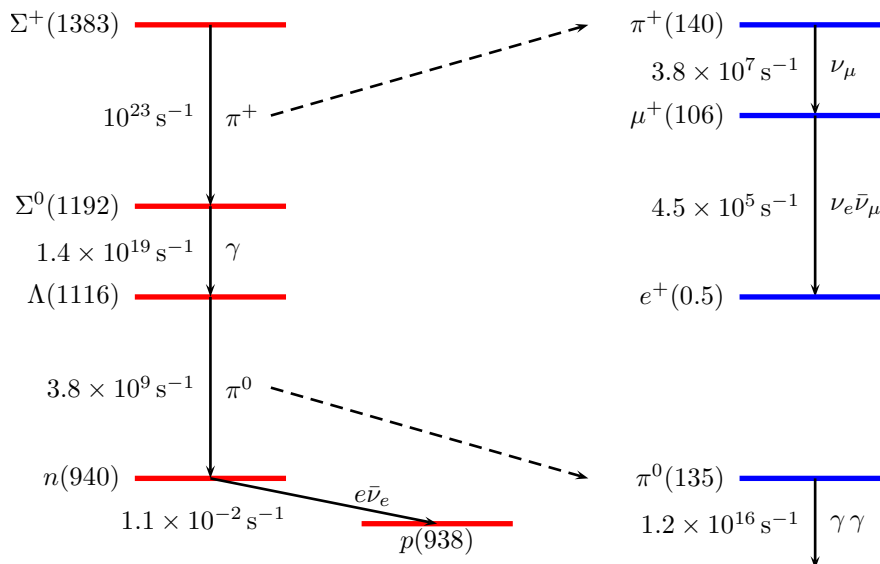Among the following reactions indicate:
1 / the two forbidden reactions
2 / the one not occurring by strong interaction

$$K^- + p \longrightarrow \overline{K}^0 + n \qquad\qquad \pi^+ + p \longrightarrow K^+ + \Sigma^+$$
$$K^- \longrightarrow \pi^- + \pi^0 \qquad\qquad K^- + p \longrightarrow \Sigma^+ + n + \pi^-$$
$$\overline{K}^0 + p \longrightarrow K^- + p + \pi^+ \qquad \bar{p} + p \longrightarrow \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^+$$

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[1]One can find $\pi^0 \propto u\bar{u} + d\bar{d}$ in the literature with another convention for the isospin multiplets of antiparticles, but the physics results do not depend on this choice of phase.

Exercice 4 :
1 / Indicate the interactions involved in each step of the decay of the Σ^+.
2 / Draw a Feynman diagram for each stage of the decay
3 / Give the final state seen in the detector

$\Sigma^+(1383)$ $\pi^+(140)$

$10^{23}\,\mathrm{s}^{-1}$ π^+ $3.8\times10^7\,\mathrm{s}^{-1}$ ν_μ

                  $\mu^+(106)$

$\Sigma^0(1192)$ $4.5\times10^5\,\mathrm{s}^{-1}$ $\nu_e\bar\nu_\mu$

$1.4\times10^{19}\,\mathrm{s}^{-1}$ γ

$\Lambda(1116)$ $e^+(0.5)$

$3.8\times10^9\,\mathrm{s}^{-1}$ π^0

$n(940)$ $\pi^0(135)$

      $e\bar\nu_e$

$1.1\times10^{-2}\,\mathrm{s}^{-1}$ $1.2\times10^{16}\,\mathrm{s}^{-1}$ $\gamma\gamma$

$p(938)$

Exercise #5: Pion-nucleon scattering
Let's consider the $\pi N \to \pi N$ scattering, with $\pi = \pi^+, \pi^0, \pi^-$ et $N = p, n$.
1 / Determine the isospin state of each possible $|\pi N\rangle$ combination.
2 / Give the 6 elastic and 4 charge-exchange possible processes. What kind of interactions are involved ? Draw a Feynman diagram for one of the charge-exchange reactions.
3 / Calculate the ratio of the following cross sections, assuming the $I = 3/2$ isospin channel is dominant near the Δ resonance:

$$R = \frac{\sigma(\pi^+ n \to \pi^0 p)}{\sigma(\pi^+ n \to \pi^+ n)}$$

Exercise #6: Invariant mass
Consider the decay in flight of a D meson of mass $M = 2\,\mathrm{GeV}/c^2$ into e, ν_e and X, where X is a hadron or a set of hadrons. The D meson has a momentum $P = 3\,\mathrm{GeV}/c$. Assume that for a particular decay, the leptons are produced at $90°$ with respect to $\mathbf{P}$, ν_e opposite to e^+, and X forward. Calculate the invariant mass m of X if the positron has a momentum $p = 0.25\,\mathrm{GeV}/c$. Explain why the mass of the positron can be neglected. Describe the decay in the rest frame of the D.

Estimate the mass of a particle decaying into two photons of momenta $\mathbf{p_1} = (0.4, 0.2)$ and $\mathbf{p_2} = (0.7, -0.2)$ (in GeV/c). Describe the decay in the rest frame.