PHY4154 Nuclear and Particle Physics

Assignment 2

(1) Griffiths 1.3

Thinking of beta decay, one could have argued that the electrons are already present in the nucleus since they come out during beta decay. Use the position-momentum uncertainty relation, $\Delta x \Delta p \geq \hbar/2$, to estimate the minimum momentum of an electron confined to a nucleus. From the relativistic energy-momentum relation, $E^2 - p^2c^2 = m^2c^4$, determine the corresponding energy and compare it to that on an electron emitted in the beta decay of tritium (~ 5 keV).

Solution: $r = 10^{-15}$m, and $\hbar = 6.58 \times 10^{-22}$ MeVs.
$\Delta x \Delta p \geq \frac{\hbar}{2}$, so $p_{min} = \frac{\hbar}{2r} = \left(\frac{\hbar c}{2r}\right)\frac{1}{c} = 98.7\ \mathrm{MeV}/c$.

$E_{min} = 98.7$ MeV, this is much much larger than the energy of the emitted electron.

(2) Griffiths 1.12/1.13

How many different meson combinations can you make with 1,2,3,4,5, or 6 different quark flavors. What is the general formula for n flavors?
How many different baryon combinations can you make with 1,2,3,4,5, or 6 different quark flavors. What is the general formula for n flavors?

Solution: For mesons, its easy. Since we need one quark and one anti-quark, if we have n flavors, the quark can be of n types, and the antiquark can be of n types, so there are n^2 possible meson combinations.
For quarks: consider n flavors.
If all three are same, then there are n combinations.
If two of a type and one different, then there are $n(n-1)$ combinations. (n ways to pick a pair, then $n-1$ ways to pick the third different).
If all three are different, then there are $n(n-1)(n-2)/6$ unique combinations.
The total is thus the sum of all three $n + n(n-1) + n(n-1)(n-2)/6$.

(3) Do the following processes/decays take place? If yes, draw Feynman diagrams showing the process/decay. If not, state why? (If a decay is merely kinematically forbidden, then draw its Feynman diagram too). The quark content of the hadrons shown here is $\eta(u\bar{u})$, $\pi^+(u\bar{d})$, $\pi^-(\bar{u}d)$, $\pi^0(d\bar{d})$, $D^+(c\bar{d})$, $\bar{K}^0(\bar{d}s)$. Use the web to find whichever masses you need, but try to find the source of that number (just as an exercise in referencing/citing).

(1) $\bar{t} \to W^- \bar{b}$: Yes. Almost the only way a $\bar{t}$ decays.

(2) $\eta \to \pi^+\pi^-\pi^0$: Yes. An OZI suppressed process.

(3) $e^+e^- \to \nu_\mu\bar{\nu}_\mu$: Yes, through a Z boson.

(4) $D^+ \to \bar{K}^0\mu^+\bar{\nu}_\mu$: No, muon number is not conserved.

(5) $d\bar{d} \to \mu^+\mu^- b\bar{b}$: Yes. Two Z's will do it (as will two γ's).

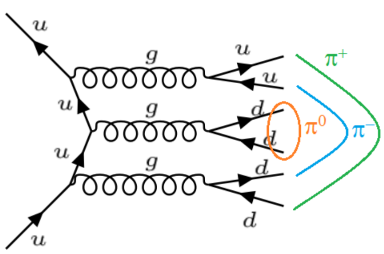
(6) $\mu^+\mu^- \to \nu_\tau\bar{\nu}_\tau\gamma$

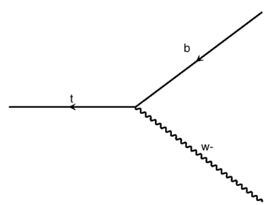
(7) $\Delta^0 \to p^+\pi^-$ (draw both strong and weak versions of this decay)

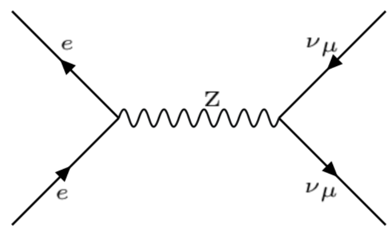
(8) $H^0 \to e^+\nu_e b\bar{b}$: No charge isnt conserved.

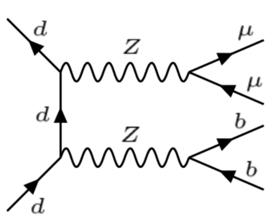
(9) $\pi^- \to \tau^-\bar{\nu}_\tau$: No, this is dynamically allowed but kinematically prohibited ($m_\pi < m_\tau$).

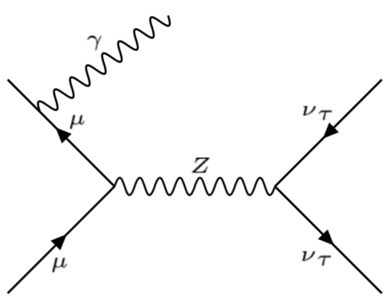
(10) $u\bar{d} \to e^+\nu_e\nu_\tau\bar{\nu}_\tau b\bar{b}$: Yes, in several ways.

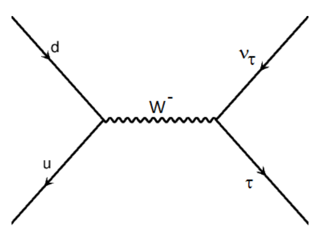


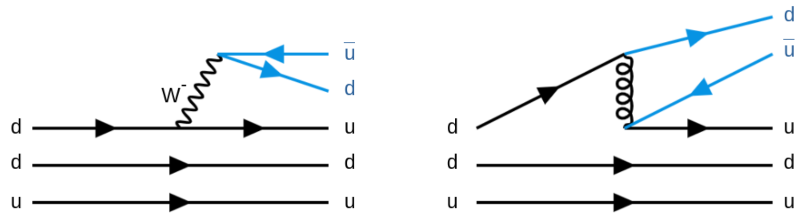




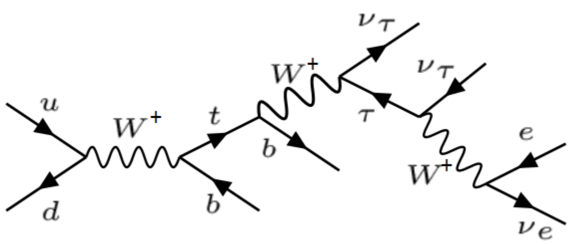


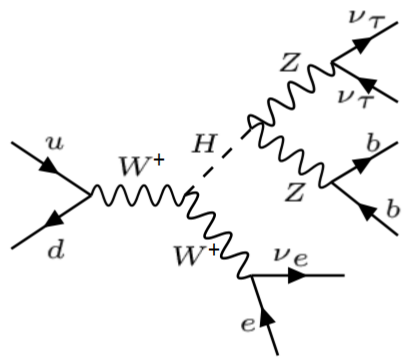






$\Delta^0 \rightarrow p\, \pi^-$





(4) Are either of these transitions possible? (as internal parts of an otherwise valid Feynman diagram)
(a) $s \rightarrow W^- u$ (b) $c \rightarrow W^+ d$
Which one is more likely?

Solution: We look at the CKM matrix to answer this question. Since $|V_{us}|$ and $|V_{cd}|$ are almost equal, both (a) and (b) are equally likely.

What about these transitions? Which one is more likely?
(a) $b \rightarrow W^- u$ (b) $t \rightarrow W^+ d$

Solution: Now since $|V_{td}| > |V_{ub}|$, $t \rightarrow W^+ d$ is more likely transition than $b \rightarrow W^- u$