1) 14.2

a) $\pi^+ \to e^+ + \gamma$ 1) need a $\nu_e$ to conserve lepton number


ok this way, in fact you're likely to see photons from these decays involving electrons

b) $\Lambda^0 \to p + K^-$

check list ✗ Q 1116 MeV − 938 MeV − 494 MeV

✓ C

see 8 P

✓ B#

✓ L#

must be strong ⇐ ✓ or quarkness ← S#

not enough Q

c) $\Omega^- \Rightarrow \Xi^- + \pi^0$ ✓ Q $1672 - 1197 - 135 > 0$

✓ C

ok P

✓ B#

✓ L#

changes by 2 S#

∠ don't know how to do this!

d) $\Lambda^0 \to \pi^+ + \pi^-$ ✓Q

✓ C

✓ P

✗ B# does not conserve baryon number

✓ L#

changes S#

e) $\Lambda^0 \to n + \gamma$ ✓Q

✓ C

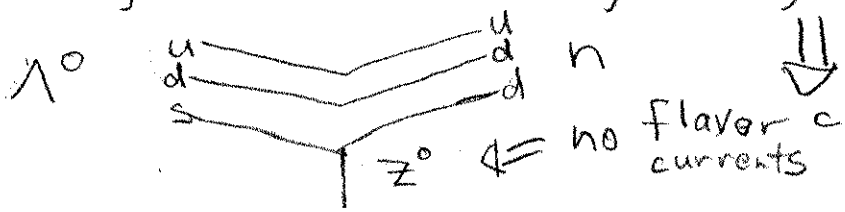
✓ P

✓ B#

✓ L#

changes by 1 S#

This decay must be weak to change strangeness, but




⇐ no flavor changing neutral currents

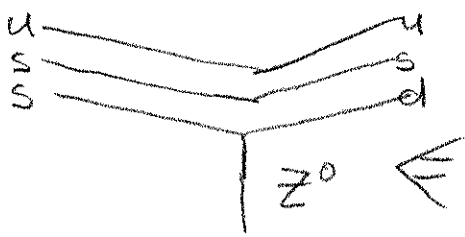
⇓ From class

f) $\Omega^- \to \Xi^0 + K^-$ ✗ Q ✓ C ✓ P ✓ $B^\#$ ✓ $L^\#$ ✓ $S^\#$ $1672 - 1315 - 494 < 0$

must be weak, changes by 1

g) $\Xi^0 \to \Sigma^0 + \pi^0$ ✓ Q ✓ C ✓ P ✓ $B^\#$ ✓ $L^\#$ ✓ $S^\#$ $1315 - 1192 - 135 > 0$

must be weak, changes by one




no flavor changing neutral currents

h) $\mu^- \to e^- + \gamma$ violates both

muon lepton number & electron lepton number

2) 14.3 a) $\nu_e + p \to n + e^+$ { these 2 particles in the beginning can have any energy }

$L_e$ 1 0 0 −1 not conserved

b) $p + p \to p + n + K^+$ strangeness not conserved

0 0 0 0 1

note: if this interaction take place with a weak current, we will produce an "s" quark which has $S = -1$, so you wouldn't expect this in any case

c) $p + p \to p + p + \Lambda^0 + K^0$

$B^\#$ 1 1 1 1 1 0

2 3

not conserved

d) $\pi^- + n \Rightarrow K^- + \Lambda^0$

$S^{\#}$ 0 0 −1 −1

$S = 0$ $S = -2$

strangeness not conserved

e) $K^- + p \to n + \Lambda^0$

$S^{\#}$ −1 0 0 −1

$B^{\#}$ 0 1 1 1

1 2

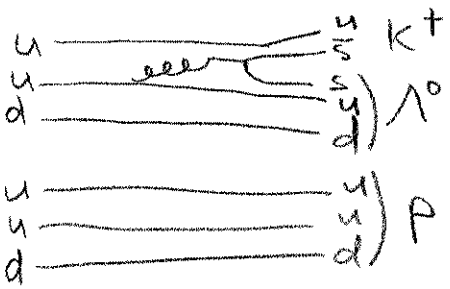
Baryon # not conserved

3) 14.15 a) $p + p \to p + \Lambda^0$

| | | | | |
|---|---|---|---|---|
| $B^{\#}$ | 1 | 1 | 1 | 1 |
| $S^{\#}$ | 0 | 0 | 0 | −1 |
| $C$ | 1 | 1 | 1 | 0 |

must be $B^{\#} = 0$, $S^{\#} = 1$, $C = 1$

$K^+$ works ok

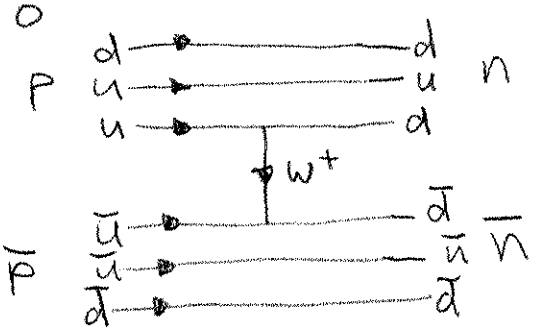



b) $p + \bar{p} \to n + \bar{n}$

| | | | |
|---|---|---|---|
| $B^{\#}$ | 1 | 1 | 1 |
| $S^{\#}$ | 0 | 0 | 0 |
| $L^{\#}$ | 0 | 0 | 0 |
| "quarkness" | 2u+1d | 2ū+1d̄ | 1u+2d |
| | $L_D = 0$ | | |

must have

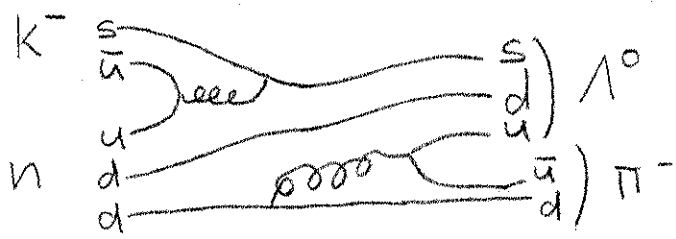
1
0
0
$-u - 2d$ $\quad \bar{d}\bar{d}u = \bar{n}$



d) $K^- + n \Rightarrow \Lambda^0 +$

| | $K^-$ | $n$ | $\Lambda^0$ | must have |
|---|---|---|---|---|
| S# | -1 | 0 | -1 | 0 |
| B# | 0 | 1 | 1 | 0 |
| L# | 0 | 0 | 0 | -1 |
| C | -1 | 0 | 0 | |

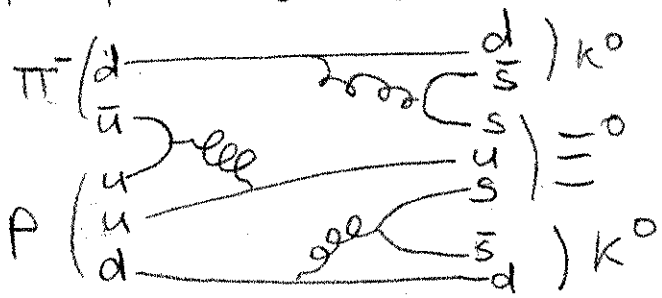
$\pi^-$ works




c) $\pi^- + p \to \Xi^0 + K^0 +$

| | $\pi^-$ | $p$ | $\Xi^0$ | $K^0$ | must have |
|---|---|---|---|---|---|
| B# | 0 | 1 | 1 | 0 | 0 |
| L# | 0 | 0 | 0 | 0 | 0 |
| S# | 0 | 0 | -2 | +1 | +1 |
| C | -1 | 1 | 0 | 0 | 0 |

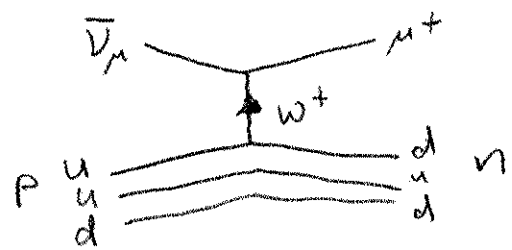
$K^0$ works




e) $\bar{\nu}_\mu + p \to n +$

| | $\bar{\nu}_\mu$ | $p$ | $n$ | must have |
|---|---|---|---|---|
| B# | 0 | 1 | 1 | 0 |
| $L_\mu$ | -1 | 0 | 0 | -1 |
| C | 0 | 1 | 0 | 1 |

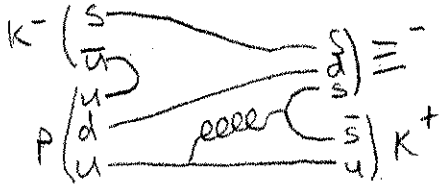
$\mu^+$ works



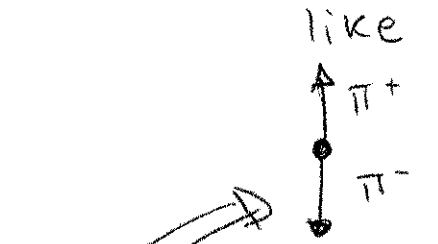

f) $K^- + p \to K^+ +$

| | $K^-$ | $p$ | $K^+$ | must have |
|---|---|---|---|---|
| B# | 0 | 1 | 0 | 1 |
| S# | -1 | 0 | 1 | -2 |
| C | -1 | 1 | 1 | -1 |

$\Xi^-$ works



4) 14.20 only way this happens is if decay occurs like




So we have a choice

1) solve in center of mass & boost
2) use invariants

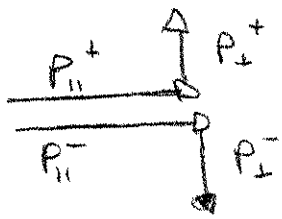
know energy & momentum conservation

$$E = KE + m_K c^2 = 2E_\pi$$

↑ lucky they're identical!

$$\vec{p}_{\pi^+} + \vec{p}_{\pi^-} = \vec{p}_{K^0}$$

vertical components cancel



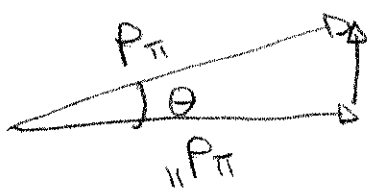

$p_{K^0} = 2p_\parallel$ & $p_\perp$ will be same as in cm

pions have an energy of $E_\pi = \frac{276\,MeV + 498\,MeV}{2} = 387\,MeV$ each

so each pion has a momentum of $\sqrt{(387^2) - (140)^2} = 360.78$ MeV/c

& we started out with $p_K = \sqrt{(276+498)^2 - (498)^2}$

$= 592.51\,MeV/c = 2p_\parallel$



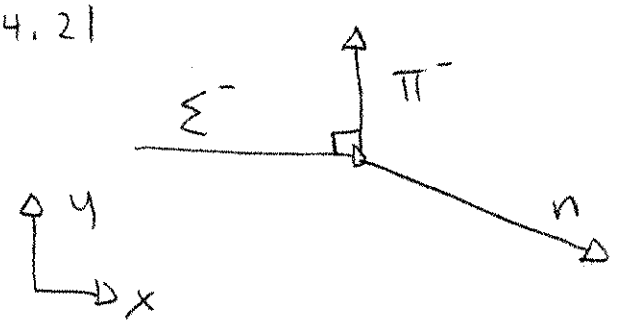

$\theta = \cos^{-1}(592.51/2)/360.78$

$= 34.8°$

check $p_\perp^2 + m_\pi^2 = \left(\frac{m_K}{2}\right)^2$ $(360.78 \sin 34.8)^2 = 4.24 \times 10^4$

$\left(\frac{m_K}{2}\right)^2 - m_\pi^2 = 4.24 \times 10^{-4}$

5) 14.21




Know $\vec{p}_{\pi^-} = -\vec{p}_{n_y}$

$\vec{p}_{\pi^-} \cdot \vec{p}_n = -2p_\pi$ useful!

use $c=1$

use invariant mass

$$m_\Sigma^2 = m_\pi^2 + m_n^2 + 2E_\pi E_n - 2\vec{p}_\pi \cdot \vec{p}_n$$

$$E_n = E_\Sigma - E_\pi$$

$$m_\Sigma^2 = m_\pi^2 + m_n^2 + 2E_\pi(E_\Sigma - E_\pi) + 2p_\pi^2$$

$$= m_\pi^2 + m_n^2 + 2E_\pi E_\Sigma \underbrace{- 2E_\pi^2 + 2p_\pi^2}_{-2m_\pi^2}$$

$$m_\Sigma^2 = m_n^2 - m_\pi^2 + 2E_\pi E_\Sigma$$

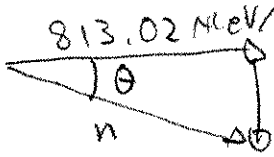
$$\frac{m_\Sigma^2 - m_n^2 + m_\pi^2}{2E_\Sigma} = E_\pi = \frac{(1197)^2 - (940)^2 + (140)^2}{2(1197+250)}$$

$KE_\pi = 196.547 - 140 = 56.55\,MeV$ $\quad = 196.547\,MeV$

$KE_n = 250 + 1197 - 196.547 - 940 = 310.45$

$$p_\pi = \sqrt{\underbrace{(196.547)^2}_{E^2} - \underbrace{(140)^2}_{m^2}} = 137.95\,MeV/c = p_{n_y}$$

$$p_{n_x} = p_\Sigma = \sqrt{\underbrace{(1197+250)^2}_{E_\Sigma^2} - \underbrace{(1197)^2}_{m_\Sigma^2}} = 813.02\,MeV/c$$




$$\theta = \tan^{-1}\left(\frac{137.95}{813.02}\right) = 9.63^\circ$$

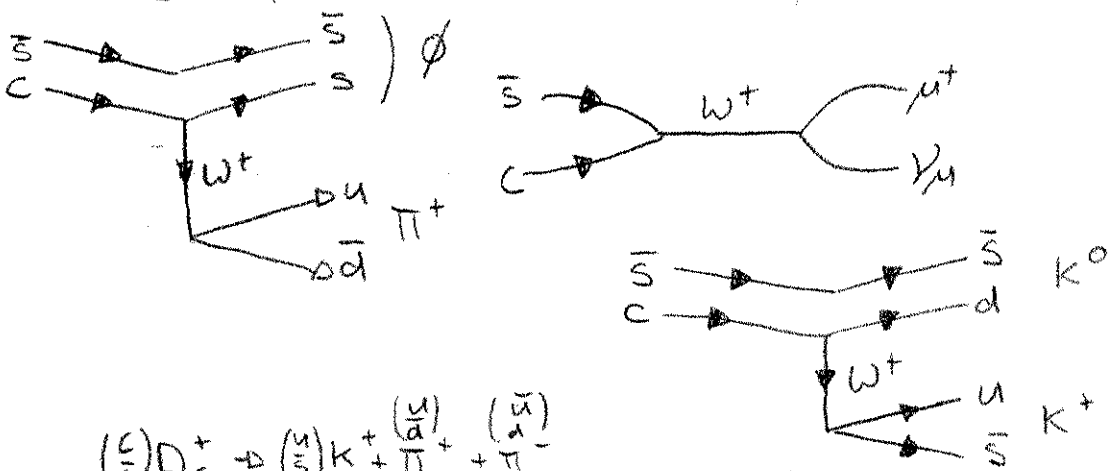
note: Books answer does not conserve energy

6) 14.25

a) Decay is weak ⟶ right time scale

b) $\begin{pmatrix} c \\ \bar{s} \end{pmatrix} D_s^+ \Rightarrow \begin{pmatrix} s \\ \bar{s} \end{pmatrix} \phi + \begin{pmatrix} u \\ \bar{d} \end{pmatrix} \pi^+$ ⟨ $\mu^+ + \nu_\mu$ ⟨ $\frac{u}{\bar{s}} K^+ + \frac{d}{\bar{s}} K^0$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C | +1 | 0 | 0 | | 0 | 0 | | 0 | 0 |
| S | +1 | 0 | 0 | | 0 | 0 | | 1 | −1 |
| | $\Delta S = -1$ | | | | $\Delta S = -1$ | | | $\Delta S = +1$ | |
| | $\Delta C = -1$ | | | | $\Delta C = -1$ | | | $\Delta C = -1$ | |

c) 


d) $\begin{pmatrix} c \\ \bar{s} \end{pmatrix} D_s^+ \to \begin{pmatrix} u \\ \bar{s} \end{pmatrix} K^+ + \begin{pmatrix} u \\ \bar{d} \end{pmatrix} \pi^+ + \begin{pmatrix} \bar{u} \\ d \end{pmatrix} \pi^-$

| | | | | |
|---|---|---|---|---|
| C | 1 | 0 | 0 | 0 |
| S | 1 | 1 | 0 | 0 |

$\frac{c}{\bar{s}} D_s^+ \to \begin{pmatrix} \bar{u} \\ s \end{pmatrix} K^- + \begin{pmatrix} u \\ \bar{d} \end{pmatrix} \pi^+ + \begin{pmatrix} u \\ \bar{d} \end{pmatrix} \pi^+$

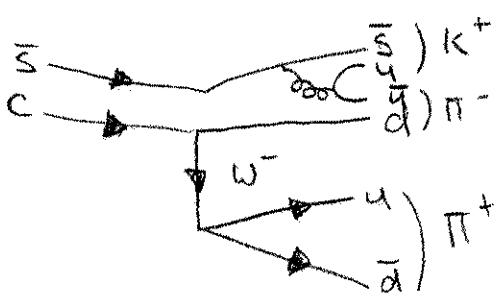
| | | | | |
|---|---|---|---|---|
| C | 1 | 0 | 0 | 0 |
| S | 1 | −1 | 0 | 0 |

$\Delta S = 0$
$\Delta C = -1$

in the decays above we had $\Delta S + \Delta C = -2, 0$ so expect this to work the same

only way to change the $\bar{s}$ is to have extra $W^+$ (very rare!)

expect




but not