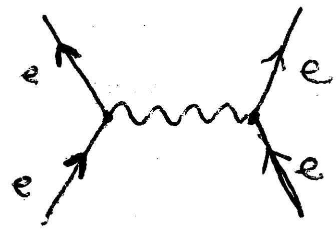
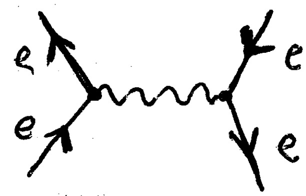
12-4 Draw a Feynman diagram illustrating each of the following scattering events.

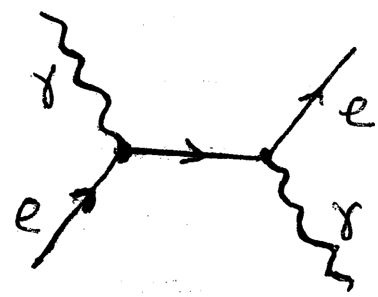
(a) electron-electron scattering



(b) electron-positron scattering



(c) Compton scattering



12-6 Proton-Antiproton Annihilation $p + \bar{p} \rightarrow \gamma + \gamma$

(a) If the proton and antiproton annihilate at rest there must be two photons... The reasoning is identical to the reasoning that $e^+ e^-$ annihilation produces 2 photons.

IF there is no momentum in the initial state, then there must be no net momentum after the annihilation. Since a single photon would carry momentum, there must be 2 photons of equal momentum (and energy) going in opposite directions.

(b) What is the energy of each photon?
Each photon has an energy equal to the rest mass energy of the proton

$$\boxed{E_\gamma = 938\ \text{MeV}}$$

(c) What is the wavelength of each photon? $E_\gamma = \frac{hc}{\lambda}$ or...

$$\lambda = \frac{hc}{E} = \frac{1240\ \text{eV}\cdot\text{nm}}{938\times10^6\ \text{eV}} = 1.32\times10^{-6}\ \text{nm} = 1.32\times10^{-15}\ \text{m}$$
$$= \underline{1.32\ \text{fm}}$$

(d) What is the frequency of each photon?

$$f = \frac{c}{\lambda} = \frac{3\times10^8\ \text{m/s}}{1.32\times10^{-15}\ \text{m}} = \underline{2.27\times10^{23}\ \text{Hz}}$$

12-7 Antiprotons are produced in the reaction

$$p + p \rightarrow p + p + p + \bar{p}$$

Why are the following reactions not possible?

(a) $p + p \rightarrow p + e^- + e^+ + \bar{p}$

The electric charge on the left side is +2 and it is 0 ~~and~~ on the right side, so this reaction does not conserve charge.
It also does not conserve Baryon number which is +2 on the left and 0 on the right.

(b) $p + p \rightarrow p + \bar{p}$

The reasons why this reaction is not possible are the same as the reasons why (a) is not possible ... ~~not~~ neither charge nor baryon number is conserved.

12-9 Name the interaction responsible for each of the following decays:

(a) $n \rightarrow p + e^- + \bar{\nu}_e$ This is negative beta decay... the WEAK interaction is responsible. signature.... neutrino.

(b) $\pi^0 \rightarrow \gamma + \gamma$ The Electromagnetic interaction is responsible for pion decay.. signature... photons

(c) $\Delta^+ \rightarrow \pi^0 + p$ The strong interaction is responsible for the decay of this "resonance" particle (see More section on p.591.)

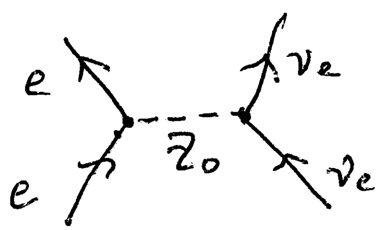
(d) $\pi^+ \rightarrow \mu^+ + \nu_\mu$ The weak Interaction is responsible for charged pion decay.. signature is neutrinos.

12-12 Which of the four fundamental interactions is most likely responsible for the following reactions

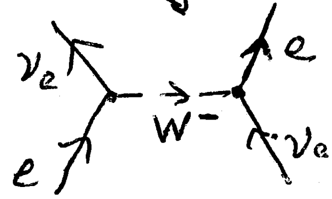
(a) ^{16}O (excited state) $\longrightarrow$ ^{16}O (ground state) + γ **Electromagnetic**

signature : photons

(b) $\nu_e + e \longrightarrow \nu_e + e$ **weak** : neutrinos only participate in weak interaction

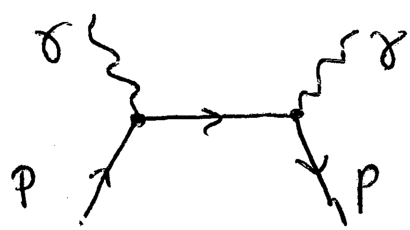


or

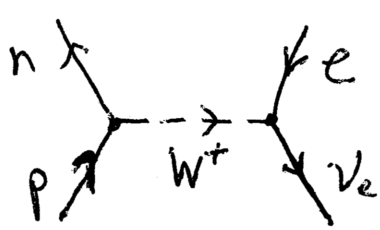


(c) $p + \bar{p} \longrightarrow \gamma + \gamma$ Electromagnetic or Strong

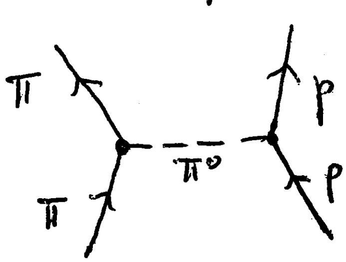
proton anti-proton annihilation



(d) $p + \bar{\nu}_e \rightarrow n + e^+$ **Weak** .. this one of the reactions that can be used to detect neutrinos



(e) $\pi^0 + p \longrightarrow \pi^0 + p$ **strong**



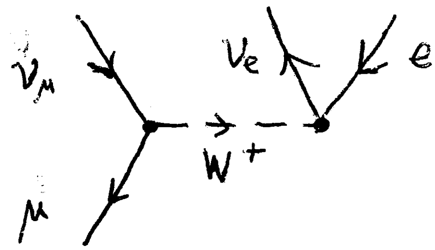
(f) $^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$ **weak**

Beta decay

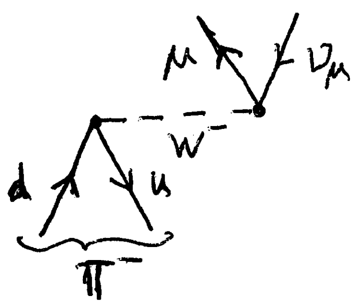
see Feynman diagram on p. 579

12-15 Draw Feynman diagrams of the following decays:

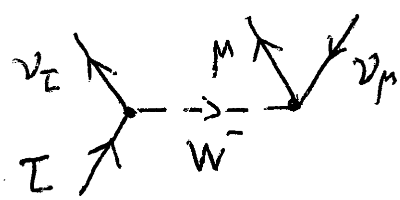
(a) $\mu^+ \to e^+ + \nu_e + \overline{\nu}_\mu$



(b) $\pi^- \to \mu^- + \overline{\nu}_\mu$



(c) $\tau^- \to \mu^- + \overline{\nu}_\mu + \nu_\tau$



12-17. State which of the decays or reactions that follow violate one or more of the conservation laws.

(a) $p \rightarrow n + e^+ + \bar{\nu}_e$ This reaction violates conservation of <u>electron lepton number</u>, L_e

$L_e = 0 \rightarrow 0 + (-1) + (-1)$

should be $p \rightarrow n + e^+ + \nu_e$

(b) $n \rightarrow p + \pi^-$ This reaction violates conservation of <u>energy</u>

since $m_n c^2 < m_p c^2 + m_\pi c^2$

$939.6\ \text{MeV} < 938.3\ \text{MeV} + 139.6\ \text{MeV}$

(c) $e^+ + e^- \rightarrow \gamma$ This reaction violates conservation of linear ~~and~~ ~~angular~~ <u>momentum</u> – Need 2 photons.

(d) $p + \bar{p} \rightarrow \gamma + \gamma$ This reaction is permitted!

(e) $\nu_e + p \rightarrow n + e^+$ This reaction violates conservation of electron lepton number, L_e.

$L_e \quad (+1) + 0 \rightarrow 0 + (-1)$

should be $\bar{\nu}_e + p \rightarrow n + e^+$

(f) $p \rightarrow \pi^+ + e^+ + e^-$ This reaction violates conservation of <u>Baryon</u> number and <u>angular momentum</u>

12-25 Find the baryon number, charge, isospin, and strangeness for the following quark combinations and identify the corresponding hadron:

	Baryon #	Charge	I_3	S	Particle
(a) uud	1	+1	$+\frac{1}{2}$	0	proton or Δ^+
(b) udd	1	0	$-\frac{1}{2}$	0	neutron or Δ^0
(c) uuu	1	+2	$+\frac{3}{2}$	0	Δ^{++} (see fig. 12-12 a)
(d) uss	1	0	$+\frac{1}{2}$	-2	Ξ^0 or Ξ^{*0}
(e) dss	1	-1	$-\frac{1}{2}$	-2	Ξ^- or Ξ^{*-}
(f) suu	1	+1	+1	-1	Σ^+ or Σ^{*+}
(g) sdd	1	-1	-1	-1	Σ^- or Σ^{*-}

12-26 Find the baryon number, charge, isospin, and strangeness for the following quark combinations and identify the corresponding hadron.

	Baryon #	Charge	Isospin (I_3)	Strangeness (S)	particle
(a) $u\bar{d}$	0	+1	+1	0	π^+
(b) $\bar{u}d$	0	−1	−1	0	π^-
(c) $u\bar{s}$	0	+1	$+\frac{1}{2}$	+1	K^+
(d) $s\bar{s}$	0	0	0	0	η^0
(e) $\bar{d}s$	0	0	$+\frac{1}{2}$	−1	$\bar{K}^0$