7.6 Exercises

Particles and Antiparticles

Ex 7.1. List five particles with their antiparticles.

Ex 7.2. The antiparticle of a proton is an antiproton. (a) List two properties of antiproton that are same as those of a proton. (b) List two properties of antiproton that are different from those of a proton.

Ex 7.3. (a) What is the antiparticle of a photon? (b) Are there other particles that have the same type of relation between particle and antiparticle? Give at least two other examples.

Ex 7.4. A positron beam of energy 2.0 MeV collides with a silver atom at rest. Two photons come out when an electron in the silver atom annihilates the positron. Assuming that the energy of the silver atom is not changed appreciably, except the loss of an electron, and that the speed of the electron in the silver atom can be ignored, what are the frequencies of the photons that come out?

Ex 7.5. In the text we have discussed the production of antiproton by a beam of protons striking a proton-rich target.

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

In addition to this reaction the reaction prducing antiproton also occurs.

$$\mathrm{p} + \mathrm{p} \rightarrow \mathrm{p} + \mathrm{p} + \mathrm{n} + \bar{\mathrm{n}}.$$

The Fundamental Forces

Ex 7.6. (a) Evaluate the electric and gravitational forces between two protons at a distance of 1 fm. (b) How many fold is the the electric force compared to the gravitational force?

Ex 7.7. Consider a particle of mass $M = m_p/10$ and speed half of the speed of light $\frac{c}{2}$. What will be the de Broglie wavelength of the particle in fm?

Ex 7.8. Pion was predicted to mediate the force between protons in the nucleus. Show that if we equate the de Broglie wavelength of the pion with speed close to the speed of light with the range of the nucleon-nucleon force we get the mass of the pion to be approximately the mass found experimentally.

Ex 7.9. The energy-time uncertainty relation is given by

$$\Delta E \Delta t \geq \hbar/2.$$

Here ΔE is the energy width of a decay process and Δt is the time over which the decay takes place. Compute the minimum energy widths in MeV for the decay involving (a) an electromagnetic interaction, $\Delta t = 10^{-9}$ s, (b) a weak interaction, $\Delta t = 10^{-20}$ s, and (c) a strong interaction, $\Delta t = 10^{-23}$ s.

Ex 7.10. The energy-time uncertainty relation is given by

$$\Delta E \Delta t \geq \hbar/2.$$

Here ΔE is the energy width of a decay process and Δt is the time over which the decay takes place. A hydrogen atom makes a quantum transition from $n = 3$ to $n = 2$ with in a time $t = 10^{-10}$ s. (a) What is the energy of the photon that comes out? (b) What is the minimum width of the spectral line plotted versus energy rather than versus wavelength? (c) What is the the minimum width of the spectral line plotted versus wavelength?

Leptons and Hadrons

Ex 7.11. Identify the conservation law(s) violated by each reaction.

(a) $\mathrm{p} + \gamma \to \mathrm{n} + \mathrm{e}^-$

(b) $\bar{\mathrm{p}} + \gamma \to \mathrm{n} + \mathrm{e}^+$

(c) $\mu^- \to \mathrm{e}^- + \bar{\nu_e}$

(d) $\tau^- \to \mathrm{e}^- + \bar{\nu_e} + \bar{\nu_\tau}$

Ex 7.12. Identify the conservation law(s) violated by each reaction.

(a) $\mathrm{p} + \bar{\mathrm{p}} \to \mathrm{n} + \mathrm{e}^+ + \mathrm{e}^-$

(b) $\Delta_0 \to \pi^+ + \pi^-$

(c) $\mathrm{p} + \mathrm{p} \to \pi^+ + \pi^+ + \pi^0$

Ex 7.13. Identify the conservation law(s) violated by each reaction.

(a) $\Sigma_0 \to \pi^+ + \pi^-$

(b) $\Omega^- \to \mathrm{n} + \mathrm{e}^- + \bar{\nu_e}$

(c) $\mathrm{p} + \mathrm{p} \to \Sigma^+ + \pi^+$

(d) $\mathrm{p} + \bar{\mathrm{p}} \to \Lambda^0 + \bar{\Lambda}^0$

Ex 7.14. In the text we have discussed the production of antiproton by a beam of protons striking a proton-rich target. The reaction is normally written as

$$\mathrm{p} + \mathrm{p} \to \mathrm{p} + \mathrm{p} + \mathrm{p} + \bar{\mathrm{p}}.$$

In addition to this reaction the reaction prducing antiproton also occurs. This reaction is written as

$$\mathrm{p} + \mathrm{p} \to \mathrm{p} + \mathrm{p} + \mathrm{n} + \bar{\mathrm{n}}.$$

Explain why we need to include p + p on the right side of these reactions.

Ex 7.15. A negative pion at rest decays into a muon and antineutrino. (a) Write the reaction. (b) Using the quark content of the pion, show the fundamental transformations and the force particles that are involved in the reaction. (c) Draw a Feynman diagram that shows the force particles as well as the initial and final particles. (d) Calculate the energies and momenta of the muon and antineutrino.

Ex 7.16. Negative pions of kinetic energy K_π strike a stationary proton target. If K_π is sufficient a K and a sigma particle will be produced by the following reaction.

$$\pi^- + \mathrm{p} \rightarrow \mathrm{K}^0 + \Sigma^0.$$

The rest mass energy of the pion is 139.5 MeV/c^2, K^0 is 497.7 MeV/c^2 and of Σ^0 is 1192.5 MeV/c^2. (a) Analyze this equation in the quark picture. (b) Draw a Feynman diagram for this reaction. (c) Use the rest masses of the reactants and products and find the value of K_π that is required for the reaction to occur. This is the threshold energy. Use relativistic formula for kinetic energy.

Ex 7.17. A kaon at rest decays into two pions by the following reaction.

$$\mathrm{K}^0 \rightarrow \pi^+ + \pi^- \quad (\sim 10^{-10}\,\mathrm{s}).$$

The rest mass energy of K^0 is 497.7 MeV/c^2 and that pions is 139.5 MeV/c^2. (a) Analyze this equation in the quark picture. (b) Draw a Feynman diagram for this reaction. (c) Compute the dissociation energy and the kinetic energies of the two pions. (d) Identify type of interaction is responsible for the decay and give your reasoning.

Ex 7.18. A Lambda particle at rest decays into a proton and a pion by the following reaction.

$$\Lambda^0 \rightarrow \mathrm{p} + \pi^- \quad (0.6 \times 10^{-23}\,\mathrm{s}).$$

The rest mass energy of Λ_0 is 1115.7 MeV/c^2 and that of negative pion is 139.5 MeV/c^2. (a) Analyze this equation in the quark picture. (b) Draw a Feynman diagram for this reaction. (c) Compute the dissociation energy and the kinetic energies of the proton and pion. (d) Identify type of interaction is responsible for the decay and give your reasoning.

The Standard Model

Ex 7.19. Two proton beams of equal energy protons are to be collided to produce more massive particles. What minimum energy for the protons do we need to produce the W^+ boson in the collision?

Ex 7.20. Identify the missing particles in the Feynman diagrams in Fig. 7.20. [There may be more than one possibility in some diagrams.]

Ex 7.21. Kaon decays in 0.9×10^{-10} sec. Suppose kaon moves with speed 0.9c. How long a track will the kaon leave?

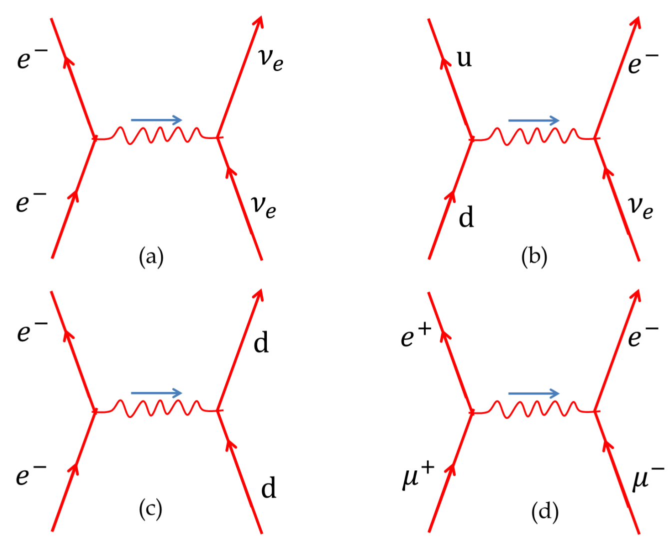

Figure 7.20: Ex. 7.20.