32–2 to 32–6 Particle Interactions, Particle Exchange

15. (I) How much energy is released in the decay

$$\pi^+ \rightarrow \mu^+ + \nu_\mu ?$$

See Table 32–2.

16. (I) About how much energy is released when a Λ^0 decays to $n + \pi^0$? (See Table 32–2.)

17. (I) How much energy is required to produce a neutron–antineutron pair?

18. (I) Estimate the range of the strong force if the mediating particle were the kaon instead of the pion.

19. (II) Two protons are heading toward each other with equal speeds. What minimum kinetic energy must each have if a π^0 meson is to be created in the process? (See Table 32–2.)

20. (II) What minimum kinetic energy must two neutrons each have if they are traveling at the same speed toward each other, collide, and produce a K^+K^- pair in addition to themselves? (See Table 32–2.)

21. (II) Estimate the range of the weak force using Eq. 32–3, given the masses of the W and Z particles as about 80 to 90 GeV/c^2.

22. (II) What are the wavelengths of the two photons produced when a proton and antiproton at rest annihilate?

23. (II) The Λ cannot decay by the following reactions. What conservation law is violated in each of the reactions?
(*a*) $\Lambda^0 \rightarrow n + \pi^-$
(*b*) $\Lambda^0 \rightarrow p + K^-$
(*c*) $\Lambda^0 \rightarrow \pi^+ + \pi^-$

24. (II) For the decay $\Lambda^0 \rightarrow p + \pi^-$, calculate (*a*) the Q-value (energy released), and (*b*) the kinetic energy of the p and π^-, assuming the Λ^0 decays from rest. (Use relativistic formulas.)

25. (II) (*a*) Show, by conserving momentum and energy, that it is impossible for an isolated electron to radiate only a single photon. (*b*) With this result in mind, how can you defend the photon exchange diagram in Fig. 32–7?

26. (II) What would be the wavelengths of the two photons produced when an electron and a positron, each with 420 keV of kinetic energy, annihilate head on?

27. (II) In the rare decay $\pi^+ \rightarrow e^+ + \nu_e$, what is the kinetic energy of the positron? Assume the π^+ decays from rest.

28. (II) Which of the following reactions and decays are possible? For those forbidden, explain what laws are violated.
(*a*) $\pi^- + p \rightarrow n + \eta^0$
(*b*) $\pi^+ + p \rightarrow n + \pi^0$
(*c*) $\pi^+ + p \rightarrow p + e^+$
(*d*) $p \rightarrow e^+ + \nu_e$
(*e*) $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu$
(*f*) $p \rightarrow n + e^+ + \nu_e$

29. (II) Calculate the kinetic energy of each of the two products in the decay $\Xi^- \rightarrow \Lambda^0 + \pi^-$. Assume the Ξ^- decays from rest.

30. (III) Could a π^+ meson be produced if a 100-MeV proton struck a proton at rest? What minimum kinetic energy must the incoming proton have?

31. (III) Calculate the maximum kinetic energy of the electron in the decay $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$. [*Hint*: in what direction do the two neutrinos move relative to the electron in order to give the latter the maximum kinetic energy? Both energy and momentum are conserved; use relativistic formulas.]

32–7 to 32–11 Resonances, Standard Model, Quarks, QCD, GUT

32. (I) Use Fig. 32–11 to estimate the energy width and then the lifetime of the Δ resonance using the uncertainty principle.

33. (I) The measured width of the J/ψ meson is 88 keV. Estimate its lifetime.

34. (I) The measured width of the ψ (3685) meson is 277 keV. Estimate its lifetime.

35. (I) What is the energy width (or uncertainty) of (*a*) η^0, and (*b*) Σ^0? See Table 32–2.

36. (I) The B^- meson is a $b\bar{u}$ quark combination. (*a*) Show that this is consistent for all quantum numbers. (*b*) What are the quark combinations for B^+, B^0, $\overline{B}^0$?

37. (II) Which of the following decays are possible? For those that are forbidden, explain which laws are violated.
(*a*) $\Xi^0 \rightarrow \Sigma^+ + \pi^-$
(*b*) $\Omega^- \rightarrow \Sigma^0 + \pi^- + \nu$
(*c*) $\Sigma^0 \rightarrow \Lambda^0 + \gamma + \gamma$

38. (II) What are the quark combinations that can form (*a*) a neutron, (*b*) an antineutron, (*c*) a Λ^0, (*d*) a $\overline{\Sigma}^0$?

39. (II) What particles do the following quark combinations produce: (*a*) uud, (*b*) $\bar{u}\bar{u}\bar{s}$, (*c*) $\bar{u}s$, (*d*) $d\bar{u}$, (*e*) $\bar{c}s$?

40. (II) What is the quark combination needed to produce a D^0 meson ($Q = B = S = 0, c = +1$)?

41. (II) The D_S^+ meson has $S = c = +1$, $B = 0$. What quark combination would produce it?

42. (II) Draw a possible Feynman diagram using quarks (as in Fig. 32–13c) for the reaction $\pi^- + p \rightarrow \pi^0 + n$.

43. (II) Draw a Feynman diagram for the reaction $n + \nu_\mu \rightarrow p + \mu^-$.