Elementary Particle Physics: 2023

Collapsar

Problem 1

(1) **Write down the three names of the fundamental interactions and draw the corresponding fundamental processes in the standard model.**

Electromagnetic Interaction:

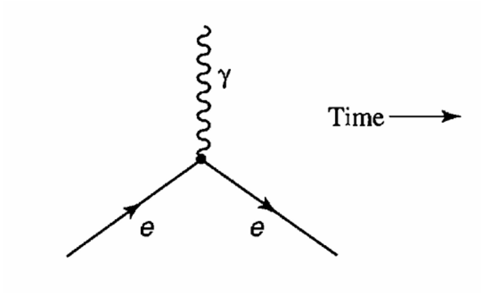

Figure 1: QED

Strong Interaction:

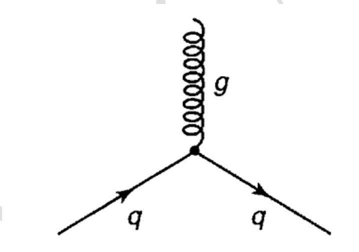

Figure 2: QCD

Weak Interaction:

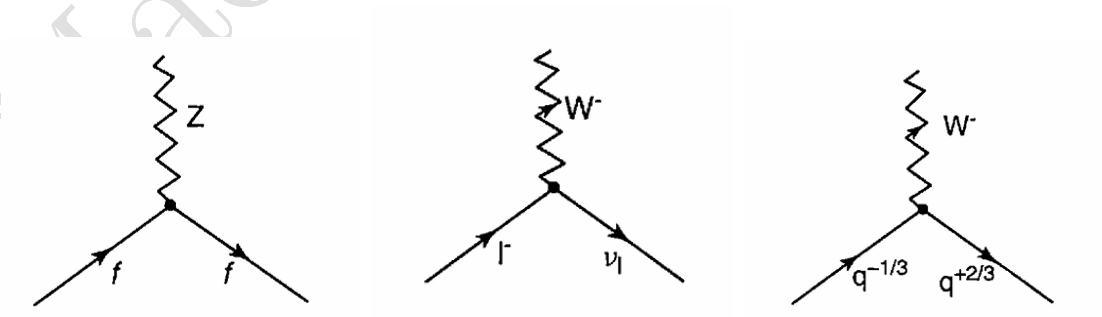

Figure 3: Neutral,Leptons and Quarks

(2) **Write down all the fundamental particles in the standard model and indicate their electric charges, spins, and muses as well as the possible interactions they may be involved.**

Quark	Symbol	Charge (e)	Spin	Mass (MeV/c²)	Interactions
Up	u	$+2/3$	$1/2$	2.16	Strong, Electromagnetic, Weak
Down	d	$-1/3$	$1/2$	4.67	Strong, Electromagnetic, Weak
Charm	c	$+2/3$	$1/2$	$1,270$	Strong, Electromagnetic, Weak
Strange	s	$-1/3$	$1/2$	93	Strong, Electromagnetic, Weak
Top	t	$+2/3$	$1/2$	$173,100$	Strong, Electromagnetic, Weak
Bottom	b	$-1/3$	$1/2$	$4,180$	Strong, Electromagnetic, Weak

Table 1: Quarks in the Standard Model

Lepton	Symbol	Charge (e)	Spin	Mass (MeV/c²)	Interactions
Electron	e^-	-1	$1/2$	0.511	Electromagnetic, Weak
Electron Neutrino	ν_e	0	$1/2$	< 0.0000022	Weak
Muon	μ^-	-1	$1/2$	105.66	Electromagnetic, Weak
Muon Neutrino	ν_μ	0	$1/2$	< 0.00017	Weak
Tau	τ^-	-1	$1/2$	$1,776.86$	Electromagnetic, Weak
Tau Neutrino	ν_τ	0	$1/2$	< 0.0155	Weak

Table 2: Leptons in the Standard Model

Boson	Symbol	Charge (e)	Spin	Mass (GeV/c²)	Interactions
Photon	γ	0	1	0	Electromagnetic
W Boson	$W^\pm$	± 1	1	80.37	Weak
Z Boson	Z^0	0	1	91.19	Weak
Gluon	g	0	1	0	Strong

Table 3: Gauge Bosons in the Standard Model

Boson	Symbol	Charge (e)	Spin	Mass (GeV/c²)	Interactions
Higgs Boson	H	0	0	125.10	Electroweak Symmetry Breaking

Table 4: Higgs Boson in the Standard Model

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(3) **Write down at lenst five: (a) pseudoscalar mesons; (b) vector mesons; and (c) baryons in terms of the fundamental particles, respectively. (For example: proton $\equiv p = uud$.)**

Meson	**Composition**
Pion (positive)	$\pi^+ = u\bar{d}$
Pion (neutral)	$\pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$
Kaon (positive)	$K^+ = u\bar{s}$
Kaon (neutral)	$K^0 = d\bar{s}$
Eta meson	$\eta = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$

Table 5: Pseudoscalar Mesons

Meson	**Composition**
Rho meson (positive)	$\rho^+ = u\bar{d}$
Rho meson (neutral)	$\rho^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$
K^* (positive)	$K^{*+} = u\bar{s}$
K^* (neutral)	$K^{*0} = d\bar{s}$
Phi meson	$\phi = s\bar{s}$

Table 6: Vector Mesons

Baryon	**Composition**
Proton	$p = uud$
Neutron	$n = udd$
Lambda baryon	$\Lambda = uds$
Sigma baryon (positive)	$\Sigma^+ = uus$
Xi baryon (neutral)	$\Xi^0 = uss$

Table 7: Baryons

(4) **Write down the gauge groups of strong and electroweak interactions of the standard model.**

- Gauge Group of Strong Interaction is $\mathrm{SU}(3)_\mathrm{C}$.
- Gauge Group of Electroweak Interaction is $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y}$.

(5) **Write down at least five names of couservation laws.**

Conservation of Energy,Momentum,Charge,Color,Baryon number,Lepton number,Flavor.

(6) **Some neutral particles are cheir own antiparticles. For example, the photon: $\bar{\gamma} = \gamma$. Why is the neutron not its own antiparticle? What is about the case for a neutrino?**

The neutron (n) is not its own antiparticle because it has conserved quantum numbers, specifically:

- **Baryon number**: The neutron has a baryon number of $+1$, while the antineutron ($\bar{n}$) has a baryon number of -1.
- **Quark content**: The neutron is composed of udd quarks, whereas the antineutron is composed of $\bar{u}\bar{d}\bar{d}$ antiquarks.

This difference in quark composition means that the neutron and antineutron have fundamentally different properties, and therefore, the neutron is not its own antiparticle.

The case for the neutrino (ν) depends on its fundamental nature, which is still an open question in particle physics:

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- If neutrinos are **Dirac particles**, they have distinct antiparticles (ν and $\bar{\nu}$), similar to how electrons and positrons are distinct.
- If neutrinos are **Majorana particles**, they are their own antiparticles ($\nu = \bar{\nu}$).

Problem 2

Examine the following processes, and state for each one whether it is possible or impossible in the standard model. In the former case, state which interaction is responsible - strong, electromagnetic or weak; in the latter case cite a conservation law that prevents it from occurring.

(1) $\pi^0 \to \gamma + \gamma$,

Possible: Electromagnetic interaction.

(2) $\pi^0 \to \gamma + \gamma + \gamma$

Impossible.

(3) $\mu^- \to \pi^- + \nu_p$

Impossible: This process violates lepton number conservation.

(4) $\tau^- \to \pi^- + \nu_\tau$

Possible: Weak interaction

(5) $p + p \to e^+ + e^+$

Impossible: This process violates lepton/baryon number conservation.

(6) $p + p \to p + p + p + \bar{p}$

Possible: Strong interaction

(7) $p \to \mathrm{n} + e^+ + \nu_c$

Impossible: This process violates lepton number conservation.

(8) $K^+ \to \pi^+ + \pi^+ + \pi^-$

Possible: Weak interaction

(9) $n \to \bar{p} + e^+ + \nu_e$

Impossible: This process violates baryon number conservation.

(10) $e^- \to e^- + \gamma$

Impossible: This process violates energy conservation.

(11) $e^+ + e^- \to \gamma$

Impossible: This process violates momentum conservation.

(12) $e^+ + e^- \to \gamma + \gamma$

Possible: Electromagnetic interaction.

Problem 3

An experiment is performed to search for evidence of the reaction $p + p \to H + K^+ + K^-$.

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(1) What are the values of electric charge, lepton number and baryon number of the particle H ? How many quarks must H contain?

- **Electric charge of H:**
- **Lepton number of H:**
- **Baryon number of H:**
- **Quark content of H:**

(2) A cheoretical calculation for the mass of this state H yields a predicted value of $m_H = 2150\text{MeV}$. What is the minimum value of incident-beam proton momentum necessary to produce this state? (Assume that the target protons are at rest.)

Problem 4

(1) Write down the possible values of (I, I_3), where I (I_3) stands for the isospin (its third component), for the following particles or systems: (a) π^+, π^-, and π^0; (b) ρ^+, ρ^-, and ρ^0; (c) $\pi^+\pi^-$, $\pi^+\pi^0, \pi^-\pi^0$ and $\pi^0\pi^0$.

(a) Pions (π^+, π^-, and π^0)

- π^+: $I = 1$, $I_3 = +1$
- π^0: $I = 1$, $I_3 = 0$
- π^-: $I = 1$, $I_3 = -1$

(b) Rho mesons (ρ^+, ρ^-, and ρ^0)

- ρ^+: $I = 1$, $I_3 = +1$
- ρ^0: $I = 1$, $I_3 = 0$
- ρ^-: $I = 1$, $I_3 = -1$

(c) Pion pairs ($\pi^+\pi^-$, $\pi^+\pi^0$, $\pi^-\pi^0$, and $\pi^0\pi^0$)

- $\pi^+\pi^-$: $I = 0, 1, 2$, and $I_3 = 0$.
- $\pi^+\pi^0$: $I = 0, 1, 2$, and $I_3 = 1$.
- $\pi^-\pi^0$:$I = 0, 1, 2$, and $I_3 = -1$.
- $\pi^0\pi^0$: $I = 0, 1, 2$, and $I_3 = 0$.

(2) Using the isospin invariance to examine the following processes and state for each one whether it is possible or impossible:

(a) $\rho^+ \to \pi^+\pi^0$; **Possible.**

(b) $\rho^- \to \pi^-\pi^0$; **Possible.**

(c) $\rho^0 \to \pi^0\pi^0$; **Possible.**

(d) $\rho^0 \to \pi^+\pi^-$.**Possible.**

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Problem 5

(1) Write down the color, spin, and flavor wave functions for n (neutron).

(2) Calculate the neutron magnetic moment in terms of those of quarks.

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