M.Sc. Examination, 2019

Semester - IV

Physics

Course: MPC-455 (Special Paper)

(Particle Physics-I)

Time: Three Hours **Full Marks: 40**

Questions are of value as indicated in the margin.

Answer ***any four*** questions. Unless otherwise specified, symbols carry their usual meanings and the Standard Model(SM) of Particle Physics is assumed.

1. (a) Define the Mandelstam variables s, t, u for the interaction $a + b \to c + d$. Show that $\mathrm{s} + \mathrm{t} + \mathrm{u}$ is Lorentz invariant.

   (b) Evaluate $\sqrt{s}$ for e^+e^- collisions with $\vec{p}_{e^+} = \{0,\ 0,\ 45\ \text{GeV}\}$ and $\vec{p}_{e^-} = \{0,\ 0,\ -45\ \text{GeV}\}$. What should be $\vec{p}_{e^+}$ to produce the same $\sqrt{s}$ if e^- is at rest? Neglect electron mass.

   (c) In the Coulomb gauge, the polarization vector of a photon satisfies, $\epsilon^0 = 0$, $\epsilon.\vec{p} = 0$. Prove the completeness relation

$$\epsilon_s^{(i)} \left(\epsilon_s^{(j)}\right)^* = \delta_{ij} - \hat{p}_i\hat{p}_j$$

   (d) The baryon $\Delta^{++}(uuu)$ has three u quarks and their spins may be in the same state. Explain if Pauli exclusion principle is violated. 2+3+2+3

2. (a) Transformation of a Dirac spinor from one inertial frame to another is given by $x'^{\mu} = \Lambda^{\mu}_{\nu}x^{\nu}$, $\psi \to \psi' = S\psi$. Show that $S^{-1}\gamma^{\mu}S = \Lambda^{\mu}_{\nu}\gamma^{\nu}$.

   (b) Show that

$$S^{\dagger}S = \gamma \begin{pmatrix} 1 & -\beta\sigma_1 \\ -\beta\sigma_1 & 1 \end{pmatrix}$$

   where,

$$S = a_+ + a_-\gamma^0\gamma^1, \quad a_{\pm} = \pm\left(\frac{\gamma \pm 1}{2}\right)^{\frac{1}{2}}, \quad \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

   (c) Show that the components of $\bar{\psi}\gamma^{\mu}\psi$ obey the Lorentz transformation. 2+3+5

3. (a) What is helicity? Draw a diagram of π^+ decay showing helicities of the particles and explain the following experimental observation.

$$\frac{\mathrm{BR}(\pi^+ \to e^+\nu_e)}{\mathrm{BR}(\pi^+ \to \mu^+\nu_{\mu})} \sim \mathcal{O}(10^{-4})$$

   (b) Draw the Feynman diagrams for the decays $D^0 \to \pi^+k^-,\ \pi^+\pi^-,\ \pi^-k^+$. Quark compositions for D^0, k^- and k^+ respectively are $c\bar{u}$, $s\bar{u}$ and $u\bar{s}$. In the spectator quark approximation estimate the ratio $\Gamma\left(D^0 \to \pi^+k^-\right) : \Gamma\left(D^0 \to \pi^+\pi^-\right) : \Gamma\left(D^0 \to \pi^-k^+\right)$.

   (c) Parity operation for a Dirac spinor is given by $\psi \to \psi' = \gamma^0\psi$. Establish that $\overline{\psi}\psi$ is a scalar and $\overline{\psi}\gamma^5\psi$ is a pseudoscalar. 3+4+3

4. (a) Use commutation properties of the Pauli spin matrices σ^i to prove that $(\vec{\sigma}.\vec{p})^2 = |\vec{p}|^2$.

   (b) Use the commutation properties of Dirac γ matrices to prove the following $\mathrm{Tr}\left(\not{a}\not{b}\not{c}\not{d}\right) = 4\left((\mathrm{a.b})(\mathrm{c.d}) - (\mathrm{a.c})(\mathrm{b.d}) + (\mathrm{a.d})(\mathrm{b.c})\right)$

   (c) At least three generations of quarks are needed to accommodate the complex phase required for CP violation factor in the CKM matrix - explain.

(d) Draw possible Feynman diagram(s) showing $K^0 - \bar{K}^0$ oscillation. 2+3+3+2

5. (a) For arbitrary real numbers c_V and c_A, calculate the trace

$$Tr\left[\gamma^\mu\left(c_V - c_A\gamma^5\right)(\not{p}_1 + m_1)\,\gamma^\mu\left(c_V - c_A\gamma^5\right)(\not{p}_2 + m_2)\right]$$

Assume commutation relations of Dirac γ matrices.

(b) Explain the results of Homestake, Super-Kamiokande, SNO, Kamland and T2K experiments in the light of neutrino oscillation. 5+5

6. (a) Briefly describe the experiment of Reines and Cowan for $\bar{\nu}_e$ detection with a schematic diagram.

(b) If the neutron is at rest calculate $E_{\nu,min}$ required, for the interaction $\nu_\mu + n \rightarrow \mu + p$.

(c) An accelerator produces a beam of ν_μ. Assuming two generation mixing of neutrinos, calculate the probability $P(\nu_\mu \rightarrow \nu_\mu)$ at a distance L.

(d) Explain the "electron appearence" result of T2K experiment in the light of neutrino oscillation. 3+2+3+2

7. (a) If neutrino is its own antiparticle it will lead to lepton number (L) violation - explain. Comment on the experimental status of this hypothesis. Comment on the theoretical and experimental status of lepton number conservation.

(b) Write a short note on the theoretical aspects and experimental status of baryon number conservation. 5+5