4. **[CO4]** *(a)* Write down $SU \otimes U(1)_Y$ gauge invariant Lagrangian for the electron-neutrino lepton pair as well as for a scalar field.

(b) Choosing an appropriate choice of the scalar field and then its vacuum expectation value, obtain the masses of the gauge bosons for breaking of above symmetry to $U(1)_Y$ through Higgs mechanism.

(c) Verify Goldstone theorem for this symmetry breaking. 3+5+2

5. **[CO2, 3]** *(a)* From free field Dirac Lagrangian, determine how Dirac field transforms under Parity, Charge conjugation transformation.

(b) Determine the how $\bar{\psi}\gamma_0\gamma_5\psi$ transform under parity transformation.

(c) State *CPT* theorem. Justify why the Lagrangian must be *CPT* invariant. 5+3+2

(OR)

5. **[CO4]** *(a)* Write down Fermi's four-fermion current-current interaction term for beta decay. Show that this interaction is parity conserving.

(b) Then write down parity violating current-current interaction term for beta decay. Show that this term violates parity.

(c) Explain with justification of the first observation in the experiment that indicates parity violation. 4+4+2

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MASTER OF SCIENCE EXAMINATION, 2025

(2nd Year, 1st Semester)

PHYSICS

PAPER : CBS/TH/202

High Energy Physics (Day)

Time : *Two Hours* *Full Marks* : 40

Answer *any* **four** questions.

1. **[CO1]** Given a Dirac spinor ψ, define its adjoint $\bar{\psi}$. Starting from the Dirac Lagrangian, $\mathcal{L} = i\bar{\psi}\gamma_m u\partial^\mu\psi - m\bar{\psi}\psi$, derive the equation it satisfies. Derive a continuity equation for the Dirac equation. Discuss the physical interpretation of this conserved current. 3+3+4

(OR)

1. **[CO1]** *(a)* Prove the following properties of the Dirac matrices :

- The Trace of the product of an odd number of γ-matrices is zero.
- $\mathrm{Tr}(\gamma^\mu\gamma^\nu) = 4g^{\mu\nu}$
- $\mathrm{Tr}(\gamma_5) = 0$

(b) Write down the Lagrangian of Quantum Electrodynamics (QED). Show that addition of a mass term $\frac{1}{2}m^2 A_\mu A^\mu$ is prohibited by gauge invariance and the photon (guage particle), must necessarily be massless. 6+4

2. **[CO2]** Define $\gamma_5 = i\gamma^0\gamma^1\gamma^2\gamma^3$. Find the value of γ_5^2 and $\{\gamma_5, \gamma^\mu\}$. Show further that $P_\pm := \frac{1 \pm \gamma_5}{2}$ define projection operators. Check under what conditions the chiral Dirac current $j_5^\mu = i\bar{\psi}\gamma^\mu\gamma_5\psi$ is conserved. 4+3+3

(OR)

2. **[CO2]** Consider the Dirac Lagrangian : $\mathcal{L} = i\bar{\psi}\gamma_m u\partial^\mu\psi - m\bar{\psi}\psi$. Check whether it is invariant under the (guage) transformations : $\psi(x) \to e^{i\alpha}\psi(x)$ and $\psi(x) \to e^{i\alpha\gamma_5}\psi(x)$, where α is a constant parameter. In case, it is an invariance/ symmetry, find the corresponding conserved current. Now consider the (local) guage transformation : $\psi(x) \to e^{i\alpha(x)}\psi(x)$, where now $\alpha(x)$ is a function of x. Repeat the same exercise to check whether the Dirac lagrangian remains invariant. 8+2

3. **[CO3]** *(a)* For the scattering process $AB \to CD$, justify how many number of independent kinematic variables are possible.

(b) Justify how many Lorentz invariant quantities can be constructed from four momentum variables p_A, p_B, p_C and p_D for this process. Then construct Mandelstam variables and show that the sum of them is $m_A^2 + m_B^2 + m_C^2 + m_D^2$. 2+(2+2+4)

(OR)

3. **[CO3]** *(a)* Write down the generic expression for the cross-section of a n-body decay of an elementary particle in terms of Feynman amplitude explaining each factors. Drawing the Feynman diagram for muon decay write down its amplitude.

(b) Derive the formula for cross-section of a scattering process using the parameters used in the experiments.

(c) Considering above two definitions of cross-section, explain the physical meaning of cross-section. (3+2)+3+2

4. **[CO4]** *(a)* Write down global $SU(2)$ gauge invariant Lagrangian for a complex scalar field and verify its invariance.

(b) Achieve local $SU(2)$ gauge invariant Lagrangian for the above Lagrangian. 4+6

(OR)