Queen Mary, University of London
Royal Holloway, University of London
University College London
Brunel University

Intercollegiate Postgraduate Course in Elementary Particle Physics

Examination Paper 1:

Section A: Symmetries and Conservation Laws (40 marks)

Section B: Particle Detectors (20 marks)

Tuesday, 15 January, 2002.

Time allowed for the Examination: 3 hours.

Answer *ALL* questions. Books and notes may be consulted.

Section A: Symmetries and Conservation Laws

Question 1

(a) [4 marks] Explain the nature of the group SU(n) and prove that it satisfies the four group axioms.

(b) [3 marks] Find the properties of the generators of SU(n) which follow from the fact that the group is i) unitary and ii) 'special'.

(c) [2 marks] Explain what a Lie Algebra is and show that the standard generators of SU(2) satisfy such an algebra. Identify the structure constants.

(d) [2 marks] Consider a two-particle quark state qq where the quarks can be considered SU(2) doublets (u, d). Identify the multiplets using Young Tableaux and calculate their multiplicities. Write down the flavour wavefunctions for the two-particle states.

(e) [4 marks] Explain briefly what is required to go from the singlet description to a complete description of the η meson.

(f) [5 marks] Write down the operator corresponding to an SU(2) rotation through an angle θ about an axis defined by the unit vector $\mathbf{n} = (n_x, n_y, n_z)$. The operator corresponding to the rotation of a two-particle state is the product of the single-particle operators, where each single-particle operator acts only on the corresponding particle state. Show that the singlet state identified in (d) is unchanged by such a transformation. (*Hint: express the operators in terms of sine and cosine functions.*)

The Pauli spin matrices:

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Question 2

(a) [**4 marks**] Draw the unitarity triangle, labelling the sides and angles. Give an example of a decay mode that can be used to determine each of the angles.

(b) [**6 marks**] Show by an appropriate diagram how a neutral B meson can oscillate into its anti-particle. Explain how this can give rise to the indirect CP violation observed in decays like $B^0 \to J/\psi K^0_S$. Briefly outline the experimental procedure for making a measurement of the CP asymmetry in this channel at a B factory experiment like BaBar.

(c) [**3 marks**] Draw the two possible Feynman diagrams for the decay $B^- \to K^-\pi^0$, labelling the CKM matrix elements. What kind of CP violation may be observed in this decay?

(d) [**7 marks**] The amplitude for the spectator (S) and dominant penguin (P) processes for the decay $B^- \to K^-\pi^0$ can be represented as:

$$\begin{aligned} S &= ae^{i\alpha}V_{ub}V^*_{us} \, , \\ P &= be^{i\beta}V_{tb}V^*_{ts} \, . \end{aligned}$$

Given that a, b, and the strong phases α, β are unaffected by the operation of CP, show that in the Wolfenstein parameterisation, the CP violating asymmetry,

$$A_{\rm CP} = \frac{\Gamma(i \to f) - \Gamma(\overline{i} \to \overline{f})}{\Gamma(i \to f) + \Gamma(\overline{i} \to \overline{f})} \, ,$$

is proportional to $\eta \sin(\alpha - \beta)$. Comment on the conditions required for this process to exhibit a significant asymmetry.

Section B: Particle Detectors

Question 1 [10 marks] In a collider experiment you wish to measure the properties of fermion-antifermion events producing either W-gamma (at a hadron collider) or Z-gamma (at a lepton collider) final states, with W or Z decaying hadronically and the gamma observed in the detector. Choose one kind of collider and say what the backgrounds might be to this process. What features must the experiment have in order to reject these backgrounds and to measure the final state distributions of the signal.

Question 2 [10 marks] For the experiment on which you are working, explain the mode of operation of one of the detector technologies involved, from the formation of the initial signal through to the input to the DAQ system. What might the alternatives have been to this technology? What are the supposed advantages of the chosen technique over the alternatives.