Institut für Theoretische Teilchenphysik

Einführung in die Flavorphysik

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Übungsblatt 2
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Aufgabe 1 (10 Punkte):

a) (2 Punkte) Starting from the standard convention for the CKM matrix find a new phase convention in which 5 CKM elements are exactly real and positive. Keep V_{ud}, V_{us}, V_{cb}, V_{tb} as they are and choose one of the remaining elements to be real. For which CKM elements is this possible?

b) (2 Punkte) In the Wolfenstein approximation one has $V_{ub} = |V_{ub}| \exp(-i\gamma)$ and $V_{td} = |V_{td}| \exp(-i\beta)$, while all other CKM elements are real. Rephase V_{ij} (Eq. (14) of the lecture) in order to express V such that the only non-zero phases are

$$\begin{array}{lllll} \text{i)} & \alpha & \text{and} & \beta \\ \text{ii)} & \alpha & \text{and} & \gamma\,. \end{array}$$

c) (3 Punkte) Show explicitly that the three angles α, β and γ of the unitarity triangle (defined in Eq. (21) of the lecture) are independent of the phase convention of V.

d) (3 Punkte) Two sides of the unitarity triangle are

$$R_u = \sqrt{\bar\rho^2 + \bar\eta^2}\,, \qquad\qquad R_t = \sqrt{(1-\bar\rho)^2 + \bar\eta^2}\,,$$

and the angles γ and β are given by

$$\gamma = \arctan\frac{\bar\eta}{\bar\rho}\,, \qquad\qquad \beta = \arctan\frac{\bar\eta}{1-\bar\rho}\,.$$

Express

- R_t and β in terms of R_u and γ,
- R_u and R_t in terms of β and γ,
- α, β and γ in terms of R_u and R_t.

Hint: This can be either solved with secondary school geometry or with Eq. (27) of the lecture.

Aufgabe 2 (10 Punkte): Jarlskog invariant For $i \neq k$ and $j \neq l$ consider

$$J = \sigma_{ik}\sigma_{jl}\,\mathrm{Im}\left[V_{ij}V_{il}^*V_{kl}V_{kj}^*\right] \qquad \text{with} \qquad \sigma_{ik} = \sum_{m=1}^{3}\epsilon_{ikm}\,.$$

a) (3 Punkte) Show that J is independent of the phase convention of V.

b) (3 Punkte) Show that J is independent of i, k, j, l.

c) (4 Punkte) Express J in terms of the (improved) Wolfenstein parameters A, λ, $\bar\rho$ and $\bar\eta$.