Supplementary Worksheet #4
Interactions & Feynman Diagrams

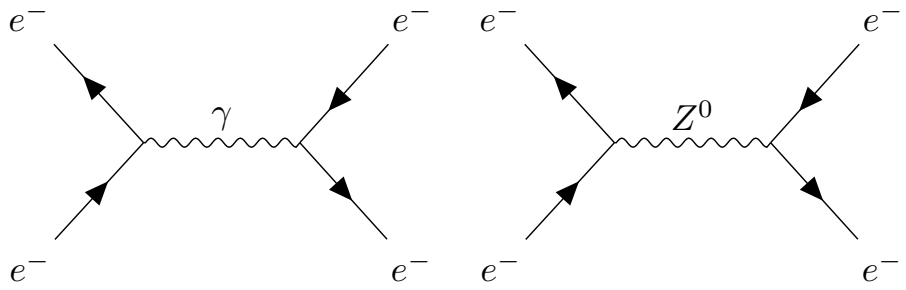
1 Quarks

1. What do you understand by the term **quark confinement**?

2 Feynman Diagrams

2. Write down the primary vertices associated with the fundamental interactions. Indicate any significant features embodied in each vertex.

3. For the following two reactions:



a) Write down the reaction equations.

b) Explain qualitatively why the probabilities differ by several orders of magnitude.

4. Crossing symmetry and Feynman diagrams:

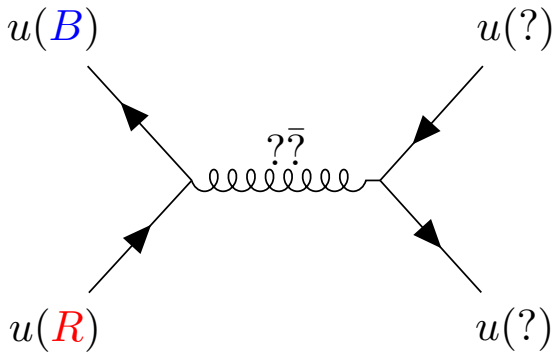
a) Using crossing symmetry, write down all physically allowed $2 \to 2$ processes related to

$$\gamma + e^- \to \gamma + e^- \tag{1}$$

b) Draw the Feynman diagram for the process in equation (1).

c) Now **twist and rotate** the diagram to obtain the Feynman diagrams for the other reactions you listed.

5. The Feynman diagram below shows a strong interaction between two up quarks (u).



a) Using the R, G, B colour basis, assign possible colour labels to all the quarks.

b) Determine the colour–anticolour combination carried by the exchanged gluon.

c) Verify that colour is conserved at each vertex.

6. Consider the decay

$$\Delta^0 \to p^+ + \pi^-. \tag{2}$$

a) Write down the quark content of each particle involved in the decay.

b) Draw a quark-level Feynman diagram for this decay.

c) Highlight if the quark flavour(s) change.

7. For the decays

$$\pi^0 \to \gamma + \gamma \tag{3}$$

and

$$\pi^+ \to \mu^+ + \nu_\mu, \tag{4}$$

a) Draw the relevant Feynman diagrams.

b) Comment on the relative lifetimes of π^0 and π^+, based on your diagrams.

3 Weak Interactions and Flavour Mixing

8. List the twelve fundamental fermions of the Standard Model, grouped by generation. Indicate how the weak interaction mixes flavours.

9. What is the significance of the Cabibbo–Kobayashi–Maskawa (CKM) matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} ?$$

10. In charged-current weak interactions, the mixing of u with the other quarks is described by:

$$u \to d' = 0.974\, d + 0.227\, s + 0.004\, b. \tag{5}$$

Explain the physical meaning of this relation.