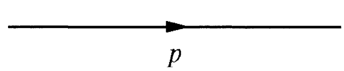
Appendix 11
The Feynman rules for QCD

We present here a list of the Feynman rules for QCD that are valid in two classes of gauge:

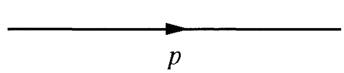
- the *covariant* gauges labelled by a parameter 'a' ($a = 1$ is the Feynman gauge; $a = 0$ the Landau gauge) in which the subsidiary condition, at least at the classical level, is $\partial^\mu A_\mu^c = 0$ for all values of the colour label c, and the gauge-fixing term in the lagrangian is $\frac{-1}{2a}\sum_c(\partial^\mu A_\mu^c)^2$;
- an *axial* gauge, one of a family again labelled by 'a', in which the subsidiary condition is $n^\mu A_\mu^c = 0$ for all c, where n^μ is a fixed space-like or null 4-vector, and where the gauge-fixing term in the lagrangian is $\frac{-1}{2a}\sum_c(n^\mu A_\mu^c)^2$.

We allow the quarks to have a mass parameter m, which should be put to zero when working with massless quarks.

(*a*) *The propagators*

lepton 

$$\frac{i(\not p + m)}{p^2 - m^2 + i\epsilon}$$

quark j 

l
$$\delta_{jl}\frac{i(\not p + m)}{p^2 - m^2 + i\epsilon}$$

In the above the arrow indicates the flow of fermion number and p is the 4-momentum in that direction. (Note: j, l are quark colour labels, b, c

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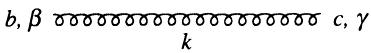
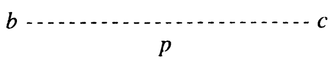
gluon and ghost colour labels.)

gluon: 

$$\delta_{bc}\frac{i}{k^2+i\epsilon}\times\begin{cases}\text{covariant gauges:}\\ \left[-g_{\beta\gamma}+(1-a)\dfrac{k_\beta k_\gamma}{k^2+i\epsilon}\right]\\ \text{axial gauges with } a=0\text{:}\\ \left[-g_{\beta\gamma}+\dfrac{n_\beta k_\gamma+n_\gamma k_\beta}{n\cdot k}-\dfrac{n^2 k_\beta k_\gamma}{(n\cdot k)^2}\right]\end{cases}$$

Note that in the above axial gauges the propagator is orthogonal to n^β, and it is orthogonal to k^β when $k^2=0$.

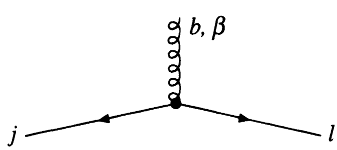
ghost:



$$\delta_{bc}\frac{i}{p^2+i\epsilon}\qquad \text{(covariant gauges only).}$$

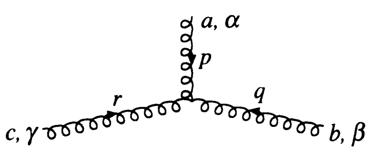
(*b*) *The vertices*

quark–gluon vertex:



$$ig(\mathbf{t}^b)_{lj}\gamma^\beta$$

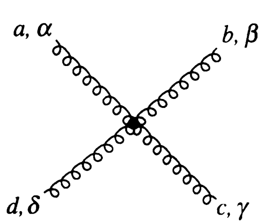
triple-gluon vertex:



$$gf_{abc}\left[g^{\alpha\beta}\,(p-q)^\gamma + g^{\beta\gamma}(q-r)^\alpha + g^{\gamma\alpha}(q-r)^\beta\right]$$

where p, q, r are momenta, with $p+q+r=0$.

quartic gluon vertex:



$$-ig^2\left[f_{eac}f_{ebd}(g^{\alpha\beta}g^{\gamma\delta}-g^{\alpha\delta}g^{\beta\gamma}) + f_{ead}f_{ebc}(g^{\alpha\beta}g^{\gamma\delta}-g^{\alpha\gamma}g^{\beta\delta}) + f_{eab}f_{ecd}(g^{\alpha\gamma}g^{\beta\delta}-g^{\alpha\delta}g^{\beta\gamma})\right]$$

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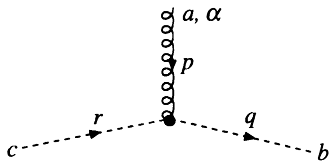
gluon–ghost vertex:



$-gf_{abc}q^{\alpha}$ (covariant gauges only)

$(p + r = q)$

Note that the ghosts are scalar fields, but a factor −1 must be included for each closed loop, as in the case for fermions.

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