Physics 4213/5213
Lecture 4 (Part 2)

1 The Gluon

Since there are now three possible strong charges for every quark species, the carrier of the strong force (the gluon) must also carry the charge. The reason for this is that otherwise only quarks with the same color would be able to interact with each other. The best data to date indicates that this is not the case, otherwise how could an anti-symmetric wave function be formed for the Δ^{++}. Further, to conserve color at each vertex, the quarks must carry a color and an anti-color giving a total of $3 \times 3 = 9$ gluons. Since one of these gluon combinations is a color singlet, it will not participate in any interaction and therefore does not exist. So finally there are only 8 gluons. Figure 1 gives an example of a basic quark gluon interaction.

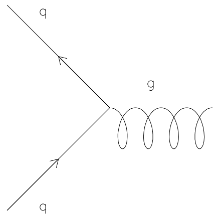

Figure 1: Example of the basic quark gluon vertex.

Given that the gluons carry the charge of the strong interaction, they must interact among themselves. Figure 2 gives the two possible gluon interaction processes. Remember these can now be used in Feynman diagrams to determine the cross sections for any process occurring. Another interesting point in strong interactions is that the more deeply quarks are probe the weaker the value of the strong coupling constant α_s becomes. This is opposite to the case of electromagnetism, where the coupling constant becomes large the more closely the electron is probed. The reason for this is not easily seen as it was for the electron, but the argument goes as follows. Quark loops in the gluon give the same effect as electrons in the photon. But now gluon loops can be added and these give the opposite effect causing the strong charge to appear smaller the closer the quark is probed. Whether the coupling constant increases or decreases with increasing momentum transfer (q^2) depends on the number of quarks and colors, if $2f - 11n$ is positive then α_s increases as in QED if it is negative then α_s decreases—f is the number of quark flavors (types) and n is the number of colors, the dividing line for 3 colors is when $2f = 32$ with current understanding there are only six quark flavors.

Based on the arguments just given, the closer together the quarks are to each other the weaker the force between them, but the larger the separation the stronger the force. This in effect states

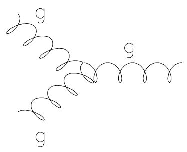

Figure 2: The basic gluon vertices.

that the quarks will be confined to bound states and cannot be free particles—this is not a proof and at present confinement has not been proven. With this picture, the force between quarks can be thought of as a spring force. The larger the separation the stronger the force pulling back until the energy in the field is large enough to create a quark anti-quark pair (see figure 3).

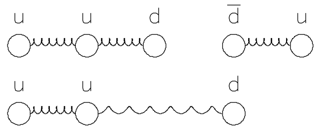

Figure 3: This figure shows the creation of a quark anti-quark pair as the initial quarks are separated.

1.1 Quark-Gluon Scattering and Jets

When two hadrons collide, what is really happening is the quarks and gluons that make up the hadrons are interacting with each other. If a quark within one of the hadrons is scattered it starts to separate from its neighbors and quark anti-quark pairs are created. In addition gluons are radiated that convert to quark anti-quark pairs. Therefore instead of seeing quarks coming out of the collision, jets of tightly collimated hadrons are seen.

1.2 The Pion and the Strong Nuclear Force

In one of the initial lectures, it was mentioned that the binding together of protons and neutrons in the nucleus was due to a force mediated by the pion. It has now been shown that the proton, neutron and pions are formed from quarks and gluons. Therefore the underlying force that binds together protons and neutrons must be due to gluons. Figure 4 shows a Feynman diagram that can explain proton-proton binding through the exchange of a pion at the quark-gluon level. Therefore, the exchange can be viewed as either pions or as quarks and gluons.

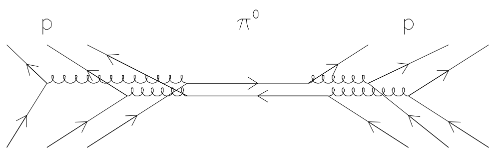

Figure 4: This shows a possible Feynman diagram for the binding of two protons through pion exchange.

2 Strong Interaction Decays

As an example of a hadron decay, consider the $\Delta^{++} \rightarrow p + \pi^+$. Recall that the Δ^{++} is composed of three u-quarks, the proton of two u-quarks and a d-quark and the π^+ is made of $u\bar{d}$. The quark composition of the three hadrons implies that to get from the Δ^{++} to the proton and pion, a $d\bar{d}$ pair needs to be created. This process can go through the radiation of a gluon off of one of the initial quarks and that gluon creating a $d\bar{d}$ pair (see fig. 5). Before claiming this to be final, the net color of the outgoing proton and pion needs to be checked—these objects must be color singlets. The gluon will carry off the color of the original quark and be transfered to the d-quark, which forms the color singlet proton. It must also carry off an anti-color associated with the new color of the u-quark that radiated off the gluon. This anti-color is given to the $\bar{d}$-quark which forms a color singlet combination with the u-quark that radiated off the gluon. Therefore, the final hadrons are still color singlets as demanded by QCD.

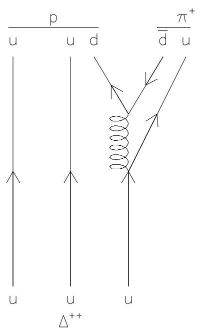

Figure 5: Feynman diagram for the decay $\Delta^{++} \rightarrow p + \pi^{+}$.