Physics 4213/5213
Lecture 3 (Part 2)

1 Introduction

In the last few lectures, electromagnetic interactions of leptons have been discussed. All these interactions involved the scattering of two incident leptons with two outgoing leptons. It was also pointed out that these process are true of any electrically charged point particles. One area not discussed, was the electromagnetic decay of particles. This is primarily due to leptons having weak decays only—the same holds for quarks. Only composite particles have electromagnetic decays and for that matter this also holds true for strong decays. Therefore in order to discuss electromagnetic and strong decays, composite particles need to be introduced—weak decays will follow later.

The only known composite particles are the hadrons. Theses are known to be composed of quarks, which are bound together through the strong interaction. Recall that hadrons are classified into two groups, those that are fermions (baryons) and those that are bosons (mesons).

Before proceeding with the lecture, the strengths of the various interaction is given. These are given in terms of both the size of the coupling constant and more importantly for experiment in terms of typical decay times:

Interaction	Coupling Constant	Typical Interaction Time
Electromagnetic	$\frac{1}{137} \approx 7 \times 10^{-3}$	10^{-20} s
Weak	$\frac{1}{29} \approx 3 \times 10^{-2}$	10^{-8} s
Strong	.1	10^{-23} s

Table 1: This table lists the coupling constants and typical decay times for the three interactions important to particle physics. Notice that the weak interaction in this table appears to be stronger that the electromagnetic interaction. This will be explained later.

This set of lectures starts by introducing conservation laws that are known for the hadrons. The known hadrons are then classified. This leads to an even simplier scheme, that leads to the introduction of the quark model and finally to a form for the strong interaction.

2 Conservation of Baryon Number

The first conservation law for strongly interacting particles is that the total number of baryons must be conserved—the number of initial baryons must equal the number of final baryons in any reaction. Many books state that the stability of the proton is due to baryon number conservation. This is in fact not necessarily true for the following reason. The proton being the lightest baryon must decay to a lepton since there are no lighter strongly interacting spin half particles. A possible decay mode is $p \rightarrow e^+ + \gamma$, this conserves energy, momentum, angular momentum and charge, but does not conserve lepton number. So it can be said that this reaction does not go due to lepton number conservation.

One correct way of showing that the number of baryons is conserved, without having to worry about other conservation laws being violated, is the collision of two protons. In principle the reaction $p + p \rightarrow \pi^+ + \pi^+$ should occur. This reaction conserves energy, momentum, angular momentum, charge and lepton number, yet this reaction has never been seen. The only type of reactions with two protons in the initial state are of the form $p + p \rightarrow p + p + X$ where X refers to a charge neutral system with zero net baryons—recall that anti-particles have oppose internal quantum number than particles, therefore X can be composed of equal numbers of baryons and anti-baryons.

There is no similar law for mesons, the total number of mesons does not have to be conserved. It will be shown shortly that this can be explained in terms of the simple quark model.

3 Strangeness

Everything in the world can be described in terms of six particles. These are the three particles that make up matter, the proton, the neutron and the electron, plus the photon that mediates the electromagnetic interaction, the pion which mediates the nuclear force and the neutrino which is emitted in radioactive nuclear decay. These six particles and no others describe the world we live in, yet a whole stream of other particles exist.

Besides a large number of other mesons and baryons that appear to be related to the pion, proton and neutron respectively, baryons and mesons that are produced jointly have also been found. The lightest of these particles are produced through the reaction $\pi^- + p \rightarrow K^0 + \Lambda$ and decay through the channels $\Lambda \rightarrow p + \pi^-$ and $K^0 \rightarrow \pi + \pi$. Both these decays occur in about 10^{-10} s making them weak decays. On the other hand the production mechanism has to go through the strong interaction, since the π^- and p are only in contact for about 6×10^{-24} s—this comes from the size of the proton and the transit time of the pion across this distance, where the pion is assumed to be traveling at the speed of light. The Λ being a baryon decays to a baryon and a meson, thereby conserving baryon number. The K^0 is a meson, so does not have to conserve baryon number. All other quantities can be shown to be conserved—energy, momentum, angular momentum and charge.

The strange thing about these particles is that they are produced in association with each other, but decay weakly into non-members of the group. Another reaction of this type is:

$$\pi^- + p \rightarrow K^+ + \Sigma^- \qquad \Sigma^- \rightarrow n + \pi^-,$$

with the lifetime of the Σ being $\approx 10^{-10}\,s$ which specifies a weak decay. The production of the Λ and the Σ in association with the K implies that there is a new conserved quantity that these new particles have. Th new quantity is conserved in strong interactions but is violated in weak interactions. The quantity is call strangeness for historical reasons. The assignment of strangeness is as follows, the baryons have strangeness -1, while the meson produced in association with the baryon has strangeness $+1$—obviously the anti-particles have opposite strangeness.

One final example of strange particle production and decay is for the Σ^0:

$$\pi^- + p \rightarrow K^+ + \Sigma^0 \qquad \Sigma^0 \rightarrow \Lambda + \gamma.$$

Here the Σ^0 decays to a strange baryon and therefore the decay is expect to go through the strong interaction, but since the lifetime of the Σ^0 is 6×10^{-20} s, the decay is through the electromagnetic interaction—strangeness is found to be conserved in electromagnetic interactions also.

4 Hadron Classification Scheme

As with the atomic elements, the first step toward understanding the hadrons is to find a way to classify them. So far the only quantities that are available are the charge, the spin (angular momentum), baryon number and strangeness. Taking the lightest spin $\frac{1}{2}$ baryons and arranging them in rows of equal strangeness with the particles arranged from left to right as most negative to most positive. This leads to figure 1. Notice that the diagonals of this figure correspond to equal charges. A similar ordering can be accomplished with the lightest (spin zero) mesons (see fig. 1).

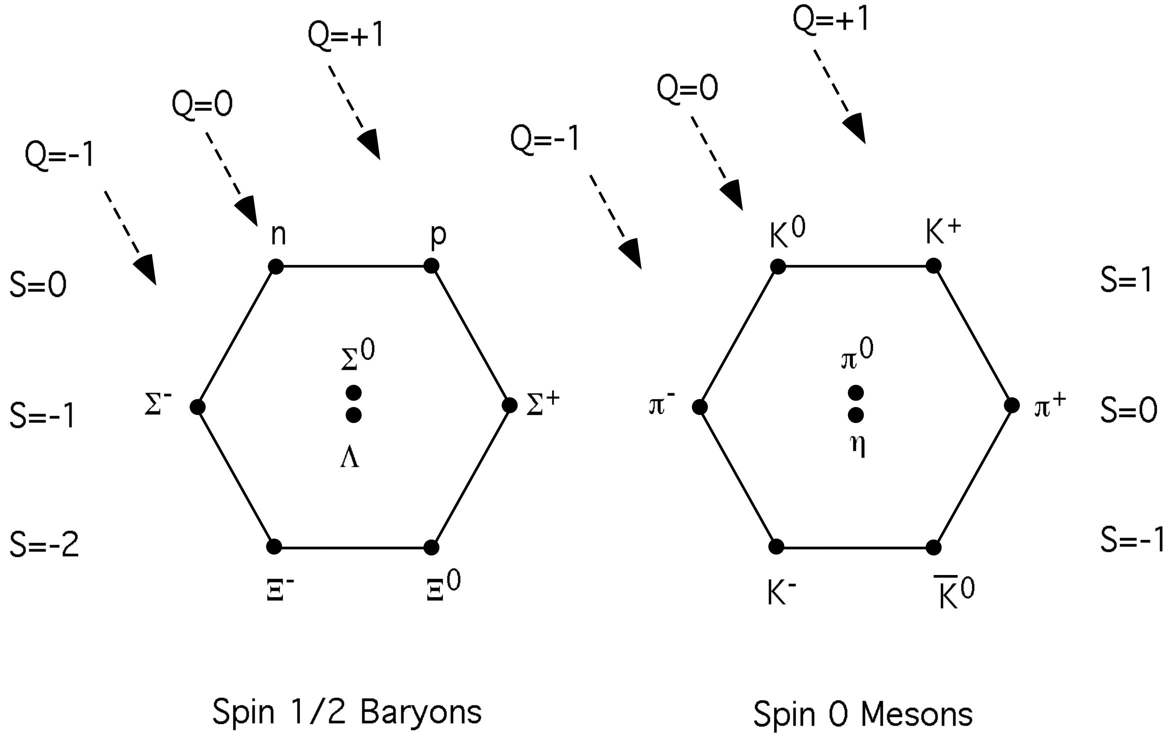

Figure 1: Organization of the lightest baryons and mesons. The baryons are all spin $\frac{1}{2}$, while the mesons are spin 0. The organization is by strangeness and charge.

To the organization of the lightest baryons and mesons can be added heavier hadrons. Figure 2 shows the next heaviest group of baryons, which are all spin $\frac{3}{2}$ baryons. This group when originally proposed had one particle missing. This was the $S = -3$ baryon referred to as the Ω^-. By looking at the regularity of the masses by row, a mass for the Ω^- was predicted, and the particle was found shortly thereafter. The success of this prediction made the scheme widely accepted, but the question remained as to what this says about the hadrons. (Note that this scheme works for heavier hadrons also.)

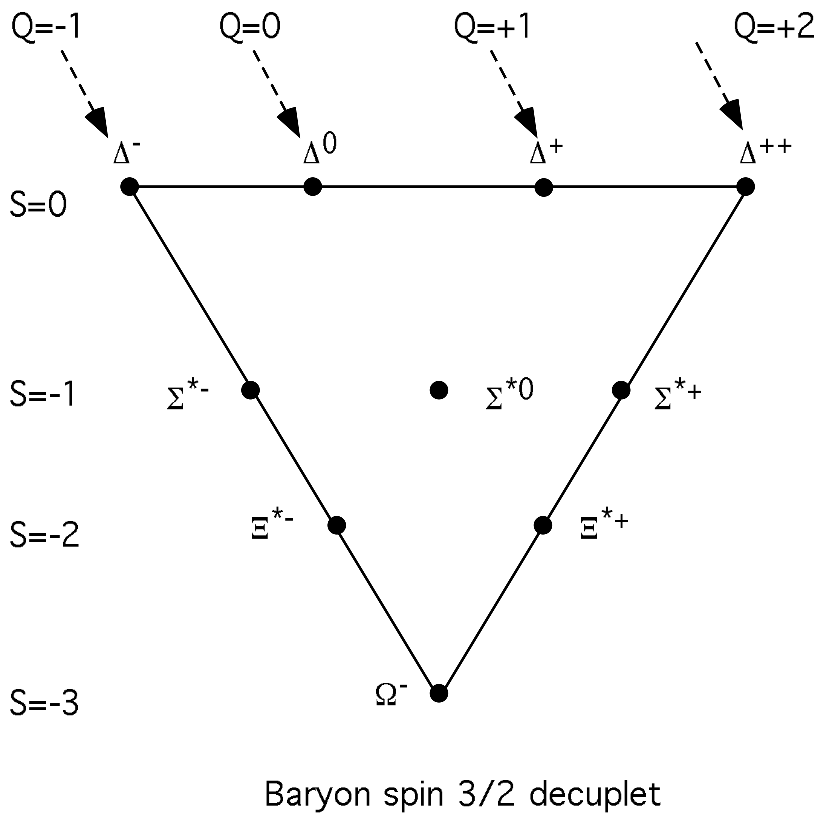

Figure 2: Organization of spin $\frac{3}{2}$ baryons by strangeness and charge.