Sea Content for Sigma Triplet using Principle of Detailed Balance

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Introduction

Hadronic physics is mainly concerned with the studies related to their structures, Parton Distribution Functions and low energy properties like magnetic moment, spin content etc. Due to complicated non-perturbative nature of strong interactions, it becomes always difficult to predict the exact structure of baryons. Therefore composition and structure of hadrons has always been of keen interest for researchers. Statistical techniques are one of the techniques that can be implemented to solve some of the key puzzles for a hadronic system.

Principle of Detailed Balance for Sigma Triplet

Statistical models have been used to find the flavor asymmetry of baryon octet in recent past by various phenomenologists [1-3]. The principle of detailed balance was first proposed by Zhang et al. [1] for proton to find $\bar{u}$ and $\bar{d}$ asymmetry from pure statistical effects which assumes the exchange between any two quark-gluon Fock states balance each other. Here we extend this principle to calculate probability associated with each Fock state. The main modification comes with the inclusion of Fock states with strange quark content.

The principle of detailed balance assumes that the composition of hadrons can be expanded by Fock states description in terms of the complete set of quark-gluon Fock states as:

$$|h\rangle = \sum_{i,j,k} c_{i,j,l,k} \, |\{q\},\{i,j,l\},\{k\}\rangle$$

Where {q} represents the valence quarks of the baryon, 'i' is the number of quark- anti quark $u\bar{u}$ pairs, 'j' is the number of quark-antiquark $d\bar{d}$ pairs, 'k' is the number of gluons, and l is the number of $s\bar{s}$ pairs. Taking the hadronic system as an ensemble of Fock states where $\rho_{i,j,l,k}$ is the probability associated to find the quark-gluon Fock states. Principle of detailed balance assumes the balancing of any two sub ensembles with each other and it can be written as:

$$\rho_{i,j,l,k} |\{q\},\{i,j,l.k\}\rangle \overset{balance}{\rightleftharpoons} \rho_{i',j',l',k'} |\{q\},\{i',j',l',k'\}\rangle$$

The principle of detailed balance includes various sub processes like $g \Leftrightarrow q\bar{q}$, $g \Leftrightarrow gg$ and $q \Leftrightarrow qg$. The general expressions of probability for the processes including the exchanges $g \Leftrightarrow gg$ and $q \Leftrightarrow qg$ are:

$$|uus,\{i,j,l,k-1\}\rangle \underset{(3+2i+2j+2l)k}{\overset{3+2i+2j+2l}{\Leftrightarrow}} |uus\{i,j,l,k\}\rangle$$

And $$\frac{\rho_{i,j,l,k}}{\rho_{i,j,l,k-1}} = \frac{(3+2i+2j+2l+k-1)}{(3+2i+2j+2l)k + \frac{k(k-1)}{2}}$$

When the process $g \Leftrightarrow q\bar{q}$ is considered:

$$|uus,i-1,j,l,k\rangle \underset{i(i+2)}{\overset{k}{\rightleftharpoons}} |uus,i,j,l,k\rangle$$

Here for come in probability, i number of $\bar{u}$ pairs can combine with i+2 number of u quarks to give a single gluon. Similar expression can be written for j number of $\bar{d}d$ pairs.

$$|uus,i,j-1,l,k\rangle \underset{j(j)}{\overset{k}{\rightleftharpoons}} |uus,i,j,l,k\rangle$$

For gluons to undergo the process $g \Leftrightarrow s\bar{s}$, it must have free energy greater than at least two times the mass of strange quark, $\varepsilon_g > 2M_s$ where M_s is the mass of strange quark. The generation of $s\bar{s}$ pair from gluons is restricted by applying a constraint in the form of $k(1-C_l)^{n-1}$ [4] where n is the total number of partons present in the Fock state. This factor is introduced from the gluon free energy distribution and applying some constraints to the momenta and total energy of partons present in the baryon. In all cases $C_{l-1} = \frac{2M_s}{M_\Sigma - 2(l-1)M_s}$, Ms is the mass of s-quark and M_Σ is the mass of sigma(Σ^+) baryon

$$\{|uus,i,j,l-1,k\rangle\} \underset{l(l+1)}{\overset{k(1-C_{l-1})^{n-1}}{\rightleftharpoons}} \{|uus,i,j,l,k\rangle\}$$

where $n = 3+2i+2j+2l+k$

$$\frac{\rho_{i,j,l,k}}{\rho_{i,j,l-1,k}} = \frac{k(1-C_{l-1})^{n-1}}{l(l+1)}$$

$$|uus,i,j,0,k\rangle \underset{1(1+1)}{\overset{k(1-C_0)^{n-2l-1}}{\rightleftharpoons}} |uus,i,j,1,k-1\rangle$$

$$\frac{\rho_{i,j,1,k-1}}{\rho_{i,j,0,k}} = \frac{(k)(1-C_0)^{n-2l-1}}{1(1+1)}$$

$$|uus,i,j,k-1,1\rangle \underset{k(k+1)}{\overset{1(1-C_{k-1})^{n-2l+k-1}}{\rightleftharpoons}} |uus,i,j,k,o\rangle$$

$$\left|uus, i, j, l+k-1, 1\right\rangle \underset{l+k(l+k+1)}{\overset{1(1-C_{l-1})^{n+k-1}}{\rightleftarrows}} \left|uus, i, j, l+k, 0\right\rangle$$

Thus the total probability for a Fock state is

$$\frac{\rho_{i,j,l,k}}{\rho_{i,j,l+k,0}} = \frac{(k(k-1)\text{——}1(1-C_0)^{n-2l-1}(1-C_1)^{n-2l}(1-C_2)^{n-2l+1}(1-C_{l-1})^{n+k-1})}{(l+k)!(l+k+1)!}$$

$$\frac{\rho_{i,j,l+k,0}}{\rho_{0,0,0,0}} = \frac{2}{i!i+2!j!(j)!(l+k)!(l+k+1)!}.$$

Using the above expressions, the individual probabilities for each Fock state can be calculated without any parameter and each value comes here in a relation with $\rho_{0,0,0,0}$ which can be estimated using the relation

$$\sum_{i,j,k} \rho_{i,j,k} = 1$$

Similarly for other members of sigma triplet, modified probability is due to difference in valence quark content and we find the modified expressions for Σ^- as:

$$\frac{\rho_{i,j,l+k,0}}{\rho_{0,0,0,0}} = \frac{2}{i!i!j!(j+2)!(l+k)!(l+k+1)!}$$

For Σ^0 as:

$$\frac{\rho_{i,j,l+k,0}}{\rho_{0,0,0,0}} = \frac{1}{i!(i+1)!j!(j+1)!(l+k)!(l+k+1)!}$$

Results and Conclusion

Probability for each Fin case of sigma triplet for each Fock state for various sub-processes can be obtained by solving the above defined expressions. The same probabilities were earlier acquired by Zhang et al. [1] and used to find flavor asymmetry ($\bar{u}$ - $\bar{d}$) for proton without including strange quark in the sea. Here we extend the same formalism to include possibility of creation and annihilation of strange quark-anti-quark pair from a gluon. Another constraint is applied here by limiting the maximum number of $s\bar{s}$ pairs as two due to momenta and mass of s-quark which limits the gluons to have larger free energy. We here test our model to find flavor asymmetry for sigma triplet and compare our results with other model. Flavor asymmetry for Σ^+, Σ^- and Σ^0 is shown in table-1 and a comparison with other models is also shown here in table-2.B. Q. Ma et al. [3] calculated the same flavor asymmetry for baryon octet using Principle of balance. Although principle of balance seems to be more generalized approach for balancing of Fock states but here we claim that inclusion of strange quark content also predicts the results almost equal to that of balance model. Also the calculations from principle of detailed balance become more approachable as compared to balance model.

We propose to apply these results further to compute low energy parameters like magnetic moment, decay ratios and spin distribution among quarks etc. for baryon octet. A suitable wave-function for baryons including sea with all possible quark-gluon Fock states can be defined. The wave-function further includes flavor, spin and color of all sea components which can provide information about the low energy parameters for baryon octet.

References

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Table 1: Flavor asymmetry for Σ^+, Σ^- and Σ^0

Hadron	Quark Content	$\bar{u}$	$\bar{d}$	$\bar{u}-\bar{d}$
Σ^+	uus	0.315	0.723	0.408
Σ^-	dds	0.722	0.316	0.406
Σ^0	uds	0.439	0.439	0

Table 2:Comparison of $\bar{u}-\bar{d}$ with other models

Model	$\bar{u}-\bar{d}$
Detailed Balance Model	0.408
Balance Model	0.41
Chiral Quark Model	0.26