Charge radii of nucleons in statistical model

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Introduction

Many experimental facilities at SELEX, JLAB collaborations [1, 2] have motivated theoreticians to calculate the mean square charge radius r_B^2. The r_B^2 is a measure of possible size of baryon. Some of the models studying the charge radii of baryon octet are cloudy bag model, heavy-baryon chiral perturbation theory etc [3].

Here, we have used valence quarks coupled with "quark sea" produced perturbatively by gluons emitted from valence quarks to calculate the charge radii of nucleons in the framework of statistical model. Statistical model has already been successful in calculating and analyzing the magnetic moments, spin distribution, decay widths of octet and magnetic moments of decuplet [4]. In view of above developments in statistical model, we have extended the model to calculate the charge radii of nucleons by including the GPM parameters.

Charge radii

The mean square radius of a given baryon is defined as:

$$\left\langle r^2 \right\rangle = \int d^3 r \rho(r) r^2 \quad \text{------ (1)}$$

where $\rho(r)$ is the charge density.

Morpurgo et al [5] developed general parameterization method (GPM) to calculate magnetic moments and masses of octet and here we have extended the use of GPM parameters to calculate the charge radii of nucleons. The charge radii operator composed of sum of one, two, three quark systems in terms of GPM parameters is defined as:

$$\hat{r}^2 = A\sum_{i=1}^{3} e_i 1 + B\sum_{i\neq j}^{3} e_i \sigma_i . \sigma_j + C\sum_{i\neq j\neq k}^{3} e_i \sigma_i . \sigma_k \quad \text{----------- (2)}$$

These GPM parameters i.e. A, B and C can further be calculated from the available experimental data on charge radii. After simplifying the operator terms in eqn. (2), we get, [6]

$$\hat{r}_B^{\,2} = (A-3B)\sum_i e_i + 3(B-C)\sum_i e_i \sigma_{iZ} \quad \text{----------- (3)}$$

So, it can be seen that calculation of charge radii basically reduces to evaluation of flavor $(\sum_i e_i)$ and spin $(\sum_i e_i \sigma_{iZ})$ structure of baryon.

Theoretical Framework

The statistical is based on assumption of hadrons as an ensemble of quark-gluon Fock states such that each Fock state shares some part of total probability associated with quark-gluon Fock states. The Fock states include different sub-processes like $q \Leftrightarrow qg, g \Leftrightarrow q\bar{q}$ etc. The methodology is based on applying the charge radii operator defined in eqn. (3) to the wave-function of octet particles. A suitable wave function for baryon decuplet is framed with inclusion of sea containing quark-gluon Fock states. The sea considered here is consist of quark-antiquark pairs muticonnected through three gluons. Due to this sea, various constants like a_0, a_8, a_{10}, b_1, b_8, b_{10}, c_8, d_8 come in baryonic wave-function. The wave-function contains suitable combinations of valence and sea quarks such that it satisfies the anti-symmetrisation and spin 1/2, flavor octet, color singlet of baryonic system and is defined as:

$$\left|\Phi_{1/2}^{\uparrow}\right\rangle = \frac{1}{N}[\Phi_1^{(1/2\uparrow)} H_0 G_1 + a_8 \Phi_8^{(1/2\uparrow)} H_0 G_8 + a_{10}\Phi_{10}^{(1/2\uparrow)} H_0 G_{\overline{10}} + b_1(\Phi_1^{(1/2)} \otimes H_1)^{\uparrow} G_1 + b_8(\Phi_8^{(1/2)} \otimes H_1)^{\uparrow} G_8 + b_{10}(\Phi_{10}^{(1/2)} \otimes H_1)^{\uparrow} G_{\overline{10}} + c_8(\Phi_8^{(3/2)} \otimes H_1)^{\uparrow} G_8 + d_8(\Phi_8^{(3/2)} \otimes H_2)^{\uparrow} G_8] \quad \text{……... (4)}$$

The first three terms in the eq. (4) is obtained by combining q^3 wave function with spin 0 (scalar sea) and next three terms are obtained by coupling q^3 with spin 1 (vector sea). The final two terms are result of coupling with spin 2 (tensor sea). The details of the above wave-function can be seen in ref. [7]. The charge radii squared r_B^2 for nucleons in octet can now be calculated by evaluating the elements of octet wave-function corresponding to operator in eqn. (3) and is given as:

$$r_B^2 = \left\langle \Phi_{1/2}^{\uparrow} \middle| \hat{r}_B^2 \middle| \Phi_{1/2}^{\uparrow} \right\rangle \quad \text{-------- (5)}$$

Results and discussion

The results for charge radii of nucleons of octet, in statistical model, are presented in Table 1.

r_B^2	Statistical model	NQM	Data[8]
r_P^2	0.760	0.813	0.877±0.007
r_n^2	-0.101	-0.138	-0.1161±0.0022

The set of GPM parameters in our case are as follows:
A=0.869, B=0.097, C=0.018 in case of proton and A=0.869, B=0.543, C=0.018 in case of neutron.

Summary and Conclusion

To summarize, statistical model is able to provide a good match of charge radii for proton (with sea) using the general parametrization method (GPM). The wavefunction constants like (a_8, a_{10} etc.) play an important role in determining the value of charge radii for the particles. The statistical model in combination with GPM is also capable of determining the charge radii values of other octet and decuplet particles.

Acknowledgements

The authors gratefully acknowledge the financial support by the Department of Science and Technology (SB/FTP/PS-037/2014), New Delhi.

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