Mass spectroscopy of Λ_c baryon using Cornell potential

Sreelakshmi M[1*] and Akhilesh Ranjan[1]
[1]Department of Physics, Manipal Institute of Technology,
Manipal Academy of Higher Education, Manipal, Karnataka, 576104 - INDIA.

Introduction

Recently, there have been significant advancements in the study of heavy hadrons. In the past twenty years more and more heavy hadrons were experimentally observed with the help of several experimental facilities like Belle, BaBar, LHCb etc. Heavy baryons contain three quarks (qqq), where at least one of the quark is heavy (charm or bottom). The Λ_c^+, the first heavy baryon was found in 1975 at the Stanford Linear Accelerator Center (SLAC). This baryon consists of a charm quark, up quark and a down quark.

Hadron spectroscopy studies the mass and decay width of hadrons. There are different methods in hadron spectroscopy, one of which is solving a phenomenological potential model to determine the energy of interquark ($q - q$) interactions. Confirming both the mass and decay width are important for verifying a potential. Quantum Chromodynamics (QCD) characteristics motivate non relativistic potential model. QCD is the theory of strong interaction between quarks and gluons. The study of heavy flavor spectroscopy is important for understanding strong interaction. One of the well studied potential is Cornell potential, which is a combination of a non perturbative color confinement potential and the perturbative one gluon exchange (OGE) interaction [1].

Methodology

A baryon contains three quarks ($q - q - q$). The three-body problem can be reduced to a two-body problem by considering the baryon as a combination of a diquark ($q - q$) and a quark (q). Therefore, the mass spectrum of the diquark should be computed first. Then, the diquark's interaction with the quark should be estimated, resulting in a two-body problem. Consequently, the Hamiltonian used for the two-body problem can be applied.

Λ_c is a singly heavy baryon with quark content udc. Here, Λ_c baryon is treated as the bound state of $[ud]$ diquark and $[c]$ quark. The interaction potential among charm quark and diquark is Cornell potential,

$$V(r) = \frac{-a}{r} + br + c, \tag{1}$$

where a, b and c are constant parameters. At short distances, there is a contribution from one gluon exchange, and at large distances, quark confinement occurs, preserving the features of QCD. The diquark mass and parameters are fixed from LQCD (Lattice Quantum Chromodynamics) studies [2], rather than being computed directly. The decay widths for the states were also computed along with mass spectra [3].

The non relativistic Hamiltonian can be written as [4],

$$H = M + \frac{p^2}{2\mu} + V(r) + V_{spin}(r). \tag{2}$$

$V(r)$ is the interaction potential between quarks. V_{spin} is the spin dependent interaction including spin-spin and spin-orbit corrections.

The time independent radial Schrödinger equation is,

$$\left[\frac{1}{2\mu}\left(\frac{-d^2}{dr^2}\right) + \frac{l(l+1)}{r^2} + V(r)\right] y(r) = Ey(r), \tag{3}$$

where, μ is the reduced mass, $\mu = \frac{m_1 m_2}{m_1+m_2}$.

*Electronic address: sreelakshmim.araam@gmail.com

The equation can be solved numerically with the help of Mathematica package [5]. Spin dependent terms were considered perturbatively.

Results and discussions

The total mass of baryon can be written as,

$$M = m_q + m_D + E_B + E_{spin}, \quad (4)$$

here, m_q is the mass of quark and m_D is the mass of diquark. E_B is the energy of baryon and E_{spin} is the spin dependent correction. Form of Cornell potential is shown in FIG I. Values for the constant parameters are given in Table I. The mass obtained for Λ_c states are given in Table II and decay width in Table III.

For the time being, the interaction between the $[ud]$ diquark and the $[c]$ quark is considered within the diquark-quark framework. However, other combinations are also possible.

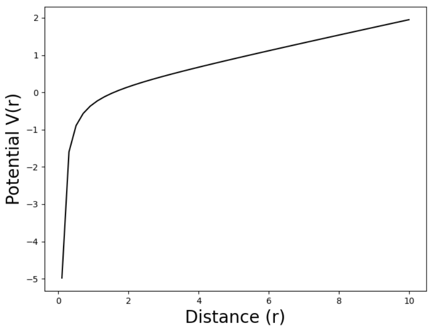

FIG. 1: Plot of Cornell potential.

TABLE I: Constant parameters used in the potential.

Parameters	Values
a	0.065 $GeV.fm$
b	1.315 $GeV.fm^{-1}$
c	-0.889 GeV
m_D	1.273 GeV
m_q	1.686 GeV

TABLE II: Mass spectra of Λ_c (GeV).

	$n^{2S+1}L_J$	Present	PDG [6]
$\Lambda_c(\frac{1}{2}^+)$	$1^2S_{1/2}$	2.300	2.284 ± 0.14
$\Lambda_c(\frac{1}{2}^-)$	$1^2P_{1/2}$	2.492	2.592 ± 0.28
$\Lambda_c(\frac{3}{2}^+)$	$1^2P_{3/2}$	2.573	2.628 ± 0.19

TABLE III: Strong one pion decay width of Λ_c (MeV).

Decay mode	Present	PDG [6]	[3]
$\Lambda_c^+(1^2P_{1/2}) \to \Sigma_c^+\pi^0$	3.836	2.6 ± 0.6	4.52
$\Lambda_c^+(1^2P_{3/2}) \to \Sigma_c^+\pi^0$	0.064	<0.97	0.033

Conclusions

Cornell potential model reproduced the Λ_c baryon spectra successfully. Results were compared with experimental results and showing good agreement. Masses of other multi quark states can also be investigated with the help of Cornell potential.

Acknowledgments

SM is grateful to Manipal Academy of Higher Education (MAHE) for the financial support under the T. M. A. Pai scholarship program.

References

[1] E. Eichten *et al*, *Phy. Rev. Lett.* **34** 369–72 (1975).
[2] K. Watanabe, N. Ishii, *Few-Body Syst* **62** 45 (2021).
[3] K. Gandhi, Z. Shah and A. K. Rai, *Eur. Phys. J. Plus* **133** 512 (2018).
[4] W. Lucha and F. F. Schoeberl, *HEPHY-PUB-621-95, UWTHPH-1995-16* (1995).
[5] W. Lucha and F. F. Schoeberl, *Int. Jn. Mod. Phys. C* **10** 607-19 (1999).
[6] P. A. Zyla *et al*, *Prog. Theor. Exp. Phys.* 083C01 (2020).