SPECTROSCOPIC STUDY AND REGGE TRAJECTORIES OF $Q\bar{q}$ AND $Q\bar{Q}$ MESONS

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Introduction

The Standard Model (SM) is a single quantum field theory that unifies our understanding of three of the four fundamental forces, i.e., the electromagnetic, weak and strong interactions. According to the theory of strong interaction known as quantum chromodynamics(QCD)- a quark and antiquark can combine to form a bound object known as meson. Heavy-light $Q\bar{q}$ system plays an important role in understanding the strong interactions between quark and antiquark, while the spectroscopy provides a powerful test of the theoretical predictions based on the quark model in the standard model. On the other hand, $Q\bar{Q}$ mesons i.e.quarkonium is a multi-scale system that probes perturbative as well as non-perturbative regimes of quantum chromodynamics(QCD)[1].

Recently, many new excited states of $Q\bar{q}$ mesons are discovered through experiments by BABAR, BELLE and CLEO and many theoretical models have made spectroscopic assignments to these states. Quite recently, LHCb has been able to discover and measure the properties of these excited states [1]. A very large amount of experimental data on the $Q\bar{Q}$ mesons has been accumulated during the last decade, that would constitute a good testing ground for non-perturbative quantum chromodynamics (QCD)[2]. Many new charmonium-like "XYZ" states have been observed at Belle, BaBar, LHC, BESIII, CLEO. The LHC experiments have demonstrated that they can discover some of the missing bottomonium states. The Belle II experiment at SuperKEKB will also offer the possibility of studying excited bottomonium states. At the same time, lattice QCD calculations of bottomonium properties have advanced considerably in recent years. The $B_c(1S)$ state is the only bound system that consists of two heavy quarks of different flavours that offers a opportunity to observe both QCD and weak interaction. The ground state $B_c(1S)$ was first observed in the CDF and D0 experiments (Tevatron) in two decay modes. Recently the ATLAS collaboration at the LHC has observed radially excited $c\bar{b}$ state (i.e, $B_c(2S)$) through the decay channel. Experimental exploration of newly observed and unconfirmed states of the $Q\bar{q}$ and $Q\bar{Q}$ mesons motivate us to carry out a broad theoretical study using potential model[3–5].

For spectroscopic study of the $Q\bar{q}$ and $Q\bar{Q}$ mesons, we employ the relativistic Hamiltonian [6, 7] in the form as given below

$$H = \sqrt{\mathbf{p}^2 + m_Q^2} + \sqrt{\mathbf{p}^2 + m_{\bar{q}}^2} + V(\mathbf{r}),$$

and the quark-antiquark potential [8]

$$V\left(r\right) = V^0\left(r\right) + \left(\frac{1}{m_Q} + \frac{1}{m_{\bar{q}}}\right) V^1\left(r\right) + V_{SD}(r)$$

We have calculated the mass spectrum of the various heavy-light and heavy-heavy flavoured mesons. The presence of light quark in the case of heavy-light mesons warrants for a relativistic treatment and in order to correctly treat the light degrees of freedom the relativistic kinetic energy terms are expanded in p^2/m. The potential employed for the present work is $-\frac{\alpha_c}{r} + Ar + V_0$. The potential has a Coulombic and linear term. To obtain the expectation values of the Hamiltonian we employ a Gaussian wave function as

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the confining interaction plays an important role in the heavy-light mesons.

The study of Regge trajectories of hadron spectra is helpful to understand the strong interactions from a different viewpoint and the open flavor hadrons are good objects for such studies. We plot the Regge trajectories in the (J, M^2) and (n_r, M^2) planes using our calculated masses for both orbitally and radially excited $Q\bar{q}$ and $Q\bar{Q}$ flavored mesons. The Regge trajectories in the (J, M^2) plane for mesons with natural $(P = (-1)^J)$ and unnatural $(P = (-1)^{J-1})$ parity and in the (n_r, M^2) plane for pseudoscalar, vector and tensor states are investigated. The slopes and intercepts for the χ^2 fitted Regge trajectories are also calculated. We use definition $J = \alpha M^2 + \alpha_0$ and $n_r = \beta M^2 + \beta_0$ to find the slope and the intercept in the (J, M^2) and (n_r, M^2) plane respectively. The estimated masses of the mesons fit well to the trajectories in (n, M^2) and (J, M^2) planes. Regge trajectories for mesons are straight and parallel lines as well as have appreciable curvature, which is flavor-dependent.

Radiative transitions probe the internal charge structure of mesons and are very useful in determining the meson structure. For the prediction of the spin parity (J^P) of the newly discovered states, the agreement with the mass spectra as well as the transitions widths is required. We evaluated the E1 dipole radiative transition widths between D, P and S wave and M1 dipole transitions widths between various S wave states for the $Q\bar{q}$ and $Q\bar{Q}$ flavored mesons.These transition widths are found to be sensitive to the effective charge thereby onto the values of constituent quark masses employed within the model.

The decay width for the leptonic decay is proportional to the square of the decay constant which in turn is related to the wavefunction overlap of the quark and anti-quark. Decay constants are thus important parameters in weak decays and are evaluated using the Van-Royen Weisskopf formula[9] both for the pseudoscalar and vector $Q\bar{q}$ and $Q\bar{Q}$ mesons, with and without QCD corrections[10]. We have also calculated leptonic and radiative-leptonic branching ratio for D, B and B_s meson, as well as dileptonic branching fractions for B and B_s mesons using the spectroscopic parameters of the present work. The annihilation decays of some $Q\bar{Q}$ states into gluons and light quarks make significant contributions to the total decay width of the states. The annihilation decays allow us to determine wave function at the origin. We calculate the S wave annihilation decays into two-photon, two lepton and two gluon for $b\bar{b}$ and $c\bar{c}$ mesons.

Particle anti-particle mixing has been of fundamental importance in testing the Standard Model and its proposed extensions. The neutral D, B and B_s mesons mix with their antiparticles leading to oscillations between the mass eigenstates [2]. Particle-antiparticle mixing parameters such as the integrated oscillation rate (χ_q), and the mass difference Δm_q are evaluated using the spectroscopic parameters of the present work for the case of D, B and B_s mesons.

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