# Three Photon decay of J/ Ψ(1S) in non-relativistic quark model

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## Introduction

Mesons exhibit several different decay modes such as leptonic, semileptonic, hadronic, radiative, two photon decays and so on. Depending on the decay products and the force involved we classify the various modes. Goal of elementary particle theory is to calculate their lifetimes and branching ratios. Using phenomenological models, we have seen, one can obtain meson mass spectra. However we know that the description of the spectra is a necessary but not a sufficient condition for aiming at a good explanation of non perturbative QCD. Hence one needs other observables which rely essentially on the same dynamical operators like transitions between various states, in order to test the model under study. So, one of the tests for the success of any theoretical model for mesons is the correct prediction of their decay rates. For this, one can take different possible decays allowed by conservation laws and governed by one of the three fundamental forces: strong, electromagnetic and weak.

In this context, the NRQM formalism is found to provide systematic treatment of the perturbative and non-perturbative components of QCD at the hadronic scale [1]. In heavy meson spectroscopy non relativistic models are found to be more suitable in studying the mass spectra, predicting the higher orbital states and other properties like leptonic and two photon decays.

Interest in Physics of charmonium has been profound in recent times due to the experimental facilities such as BES, CLEO-c and B factories with a higher initial energy of the electron and positron beams. The $J/\psi$ was the first charmonium state discovered, in 1974[2]. It is the lowest $^3S_1$ $c\bar{c}$ state and thus can couple directly to virtual photons produced in $e^+e^-$ collisions [3]. The most precise mass determination to date comes from the KEDR collaboration[4], m($J/\psi$)=3096.917±0.010±0.007 MeV, a relative uncertainty of 4 x $10^{-6}$. New leptonic $J/\psi$ branching ratios were measured by the CLEO Collaboration by comparing the transitions $\psi(2S)\to\pi^+\pi^- J/\psi(1S)\to\pi^+\pi^- X$ with $\psi(2S)\to\pi^+\pi^- J/\psi(1S)\to\pi^+\pi^-\ell^+\ell^-$.

In this paper we have calculated the three photon decay width of $J/\psi$ using non relativistic quark model. The three photon decay, in spite of its small rate, presents a very interesting object for a study of dynamics of charmonium.

## Results and discussions

The $^3S_1$ state of positronium, ortho-positronium, decays almost exclusively to $3\gamma$ and has played an important role in precision tests of QED. The analogous decay in the quarkonium system, $J/\psi(1S)\to\gamma\gamma\gamma$, has recently been reported by the CLEO-c experiment [5]. Like ortho-positronium for QED, this $J/\psi(1S)$ decay sheds light on our study of QCD. The rate of the decay in the potential approach is given by

$$\Gamma = \frac{16(\pi^2 - 9)e_c^6\alpha^3}{3\pi M^2}\left|R_S(0)\right|^2$$

Adding to the expression, the first order QCD correction we have the following expression

$$\Gamma' = \frac{16(\pi^2 - 9)e_c^6\alpha^3}{3\pi M^2}\left|R_S(0)\right|^2 (1-12.6\frac{\alpha_s}{\pi})$$

where $e_c$ is the charge content of *c* quark, $\alpha$ is the fine structure constant, $\left|R_S(0)\right|^2$ is the square of the radial wave-function at the origin, $\alpha_s$ is the coupling constant and M is the mass of the charmonium.

We have chosen the parameters of the non relativistic quark model from the data on the known states of charmonium which successfully reproduce the masses of $c\overline{c}$ states to calculate the $3\gamma$ decay width of $J/\psi$. The parameters are given in the table 1. Our calculated values are given in the table 2.

As we compare the values in the table 2 the QCD radiative correction is large. The $3\gamma$ decay rate without QCD correction is 2.92 eV corresponding to the branching fraction $B(J/\psi \to 3\gamma) \sim 3\times10^{-5}$ which can be compared with the upper limit $5.5\times10^{-5}$ given in PDG[6].

## Conclusions

The decays ${}^3S_1 \to 3\gamma$ have very small rates proportional to $\alpha^3$. However, a measurement of such decay for the $J/\psi$ resonance does not appear to be unrealistic. We have calculated the decay rates both with and without QCD correction and the value without the QCD correction appears to be closer to the experimentally observed value. We conclude that the non relativistic quark model has the right prediction for the three photon decay width with the parameters used to calculate the masses of charmonium states.

**Table 1 Parameters used in our model**

| | | |
|---|---|---|
| b | 0.325 | fm |
| $M_c$ | 1270 | MeV |
| $a_c$ | 260 | MeV $fm^{-1}$ |
| $\alpha_s$ | 0.2 | |

**Table 2 Three photon decay width with and without QCD correction (in eV)**

| Meson | $\Gamma'$ | $\Gamma$ |
|---|---|---|
| $J/\psi$ | 0.58 | 2.92 |

## References

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