Charmonium Properties in a Screened Potential Model

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Introduction

There are various nonrelativistic potential models proposed to understand the quarkonium spectra. The specific form of the QCD potential in the whole range of distances is not known. The conventional quenched (Coulomb plus linear confinement) models overestimate the masses of quarkonia in the energy region above the open-flavor thresholds. Relativistic effects are of importance in quarkonia, as these effects give rise to QQ pairs from the vacuum. Therefore the QQ interaction may be affected by the presence of sea quarks. The unquenched lattice QCD simulations suggests that the inclusion of sea quarks introduce two physical effects, one at large distances and one at small distances [1, 2]. The presence of sea quarks slows down the running of the QCD coupling as a function of the scale with respect to the quenched approximation. When running the coupling from an infra-red hadronic reference scale down to short distances, the effective Coulomb coupling in presence of sea quarks remains stronger than in the quenched case [2]. From the analysis of hadron spectrum using dynamical fermions, it has been reported that there are indications of a qualitatively different behaviour in the Coulombic range at small distances [3]. Thus the sea quarks will change the QCD potential at short distances. While the vacuum polarisation due to gluons has an anti-screening effect on fundamental sources, sea quarks result in screening [1]. Therefore the original Coulomb coupling may be affected by the presence of sea quarks.

Taking into consideration the above factors, in this work, we have investigated the charmonium spectrum in a screened potential model.

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Theoretical Model

Screening effects were parametrized in exploratory lattice studies by a screened funnel potential [4]. Various screened models for quarkonia can be found in literature [5, 6]. In the present work we have investigated the charmonium spectra using the following form for the potential

$$V(r) = -\frac{4A}{3r}\exp(-\mu r) + B(1-\exp(-\mu r)) - C$$

To obtain the spectrum we have solved the nonrelativistic Hamiltonian

$$H = M + \frac{p^2}{2\mu} + V(r), \qquad (1)$$

numerically using Mathematica [7]. The spin-dependent interactions are added perturbatively to the previously obtained spin-averaged spectrum. The model parameters and the wavefunction that reproduce the mass spectra are used to investigate the decay constants, leptonic decay widths, two-photon and two-gluon decay widths.

Results and Discussions

In the present work, we have used a screened potential model to obtain the spectra and decay widths of charmonium. The results are tabulated in Table I and Table II. From our calculations we conclude that the screened potential model used in our analysis gives a reasonably good prediction for the spectra and decay rates of charmonium in agreement with the experiment.

TABLE I: $c\bar{c}$ spectrum (in MeV)

State	Present	Exp.[8]	[5]	[9]	[10]
J/ψ	3097	3097	3097	3090	3099
$\psi(2S)$	3682	3686	3673	3672	3615
$\psi(3S)$	4040	4039	4022	4072	3962
$\psi(4S)$	4301	4263	4273	4406	4240
$\psi(5S)$	4503	4421	4463		4478
$\psi(6S)$	4662		4608		4690
$\eta(1S)$	2978	2980	2979	2982	2976
$\eta(2S)$	3632	3637	3623	3630	3533
$\eta(3S)$	4008		3991	4043	3895
h_c	3527	3526	3519	3516	3514
χ_{c0}	3440	3415	3433	3424	3466
χ_{c1}	3517	3511	3510	3505	3514
χ_{c2}	3562	3556	3554	3556	3524
$^1D_1$	3808		3796	3799	3844
$^3D_1$	3798	3775	3787	3785	3860
$^3D_2$	3809		3798	3800	3854
$^3D_3$	3811		3799	3806	3838

TABLE II: Leptonic Decay Widths (in keV)

State	Present	Exp.[8]	[5]	[9]
J/ψ	5.82	5.55	6.60	12.13
$\psi(2S)$	2.12	2.33	2.40	5.03
$\psi(3S)$	1.26	0.86	1.42	3.48
$\psi(4S)$	0.86	0.58	0.97	2.63
$^3D_1$	0.025	0.259	0.031	0.056

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