$b\bar{b}$ spectroscopy

Suraj N. Gupta and Stanley F. Radford
Department of Physics, Wayne State University, Detroit, Michigan 48202

Wayne W. Repko
Department of Physics, Michigan State University, East Lansing, Michigan 48824
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We comment on the significance of the experimental findings in $b\bar{b}$ spectroscopy at the Cornell Electron Storage Ring, and provide new theoretical results for $E1$ transitions in $b\bar{b}$ based upon our quantum-chromodynamic potential model for quarkonia.

The $2P$ and $1P$ states of $b\bar{b}$ and their fine-structure splittings have been observed in a series of experiments at the Cornell Electron Storage Ring by Han *et al.*,[1] Klopfenstein *et al.*,[2] and Haas *et al.*[3] We would like to comment on the significance of the experimental findings of these authors, and provide new theoretical results for $E1$ transitions in $b\bar{b}$ based upon our quantum-chromodynamic potential model for quarkonia.[4]

As indicated by Haas *et al.*[3] and Gilchriese,[5] the Cornell experimental results for the center of gravity and fine-structure splittings of the P states are in excellent agreement with our theoretical predictions.[4] It is also noteworthy that these experimental results rule out a non-quantum-chromodynamic potential model.[6] It is generally recognized that the spectroscopy of heavy quarkonia offers a unique testing ground for quantum chromodynamics because it does not involve the use of prescriptions such as hadronization. Thus, the overall agreement between our theoretical predictions for $b\bar{b}$ and the experimental findings represents a clear *quantitative* triumph of quantum chromodynamics.

In order to further compare the theoretical and experimental results for $b\bar{b}$, we have calculated the widths for the $E1$ transitions

$$\Gamma_{E1}(^3S_1 \rightarrow {}^3P_J) = \frac{4}{9}\frac{2J+1}{3}\alpha e_Q^2 k_J^3 |r_{fi}|^2 ,$$

$$\Gamma_{E1}(^3P_J \rightarrow {}^3S_1) = \tfrac{4}{9}\alpha e_Q^2 k_J^3 |r_{fi}|^2 ,$$

and our results are given in Tables I and II. These widths have been obtained purely theoretically without any input from the experimental results of Refs. 1–3, and they are in agreement with the experimental data for those transitions that have been observed so far.

Further experimental and theoretical investigations of the $b\bar{b}$ system are highly desirable. Indeed, it is hoped that $b\bar{b}$ will become the hydrogen atom of quantum chromodynamics.[5]

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TABLE I. Theoretical widths for the $E1$ transitions $^3S_1 \rightarrow {}^3P_J$.

Transition	k_J (MeV)	$\|r_{fi}\|$ (GeV^{-1})	Γ_{E1} (keV)
$3\,^3S_1 \rightarrow 2\,^3P_2$	89	2.60	2.9
$\rightarrow 2\,^3P_1$	103		2.7
$\rightarrow 2\,^3P_0$	123		1.5
Total			7.1
$3\,^3S_1 \rightarrow 1\,^3P_2$	445	0.01	4.6×10^{-3}
$\rightarrow 1\,^3P_1$	462		3.1×10^{-3}
$\rightarrow 1\,^3P_0$	487		1.2×10^{-3}
Total			8.9×10^{-3}
$2\,^3S_1 \rightarrow 1\,^3P_2$	103	1.64	1.8
$\rightarrow 1\,^3P_1$	120		1.7
$\rightarrow 1\,^3P_0$	145		1.0
Total			4.5

TABLE II. Theoretical widths for the $E1$ transitions $^3P_J \rightarrow {}^3S_1$.

Transition	k_J (MeV)	$\|r_{fi}\|$ (GeV^{-1})	Γ_{E1} (keV)
$2\,^3P_2 \rightarrow 2\,^3S_1$	253	1.99	23.0
$2\,^3P_1 \rightarrow$	239		19.4
$2\,^3P_0 \rightarrow$	219		14.9
Total			57.3
$2\,^3P_2 \rightarrow 1\,^3S_1$	804	0.23	9.7
$2\,^3P_1 \rightarrow$	790		9.2
$2\,^3P_0 \rightarrow$	770		8.5
Total			27.4
$1\,^3P_2 \rightarrow 1\,^3S_1$	448	1.18	45.4
$1\,^3P_1 \rightarrow$	431		40.4
$1\,^3P_0 \rightarrow$	406		33.8
Total			119.6

[1]K. Han *et al.*, Phys. Rev. Lett. **49**, 1612 (1982).
[2]C. Klopfenstein *et al.*, Phys. Rev. Lett. **51**, 160 (1983).
[3]P. Haas *et al.*, Phys. Rev. Lett. **52**, 799 (1984).
[4]S. N. Gupta, S. F. Radford, and W. W. Repko, Phys. Rev. D **26**, 3305 (1982).
[5]M. G. D. Gilchriese, in *Particles and Fields—1983,* proceedings of the Meeting of the APS Division of Particles and Fields, Blacksburg, Virginia, edited by A. Abashian (AIP, New York, 1984), p. 93.
[6]A. Khare, Phys. Lett. **98B**, 385 (1981).