# Will dimesons discriminate between meson-exchange and gluon-exchange effective quark-quark interaction?*

D. Janc and M. Rosina**

Faculty of Mathematics and Physics, University of Ljubljana,
Jadranska 19, P.O. Box 2964, 1001 Ljubljana, Slovenia,
and J. Stefan Institute, Ljubljana, Slovenia

**Abstract.** A phenomenological estimate is derived such that the binding energies of heavy dimesons are expressed as combinations of masses of different mesons and baryons. We get $\bar{b}\bar{b}qq$ (I=0, J=1) bound by about 100 MeV and $\bar{c}\bar{c}qq$ unbound. The result is almost model independent and should come out similar in any model which reproduces $\Lambda_b$ and $\Lambda_c$ correctly. Therefore it does not discriminate between meson-exchange and gluon-exchange interaction of the two light quarks.

## 1 Introduction

The constituent quark model has been rather successful in describing the properties of individual hadrons [1–3]. The extrapolation to two-hadron systems is, however, still rather uncertain. Much can be learned by studying heavy two-meson systems which decay only weakly. Although difficult to detect because of a low production cross section, they are interesting theoreticaly, to confront different models. The detailed calculations in the literature [4,5] rely on particular quark models, therefore we attempt an almost model-independent phenomenological estimate.

Our estimate of the binding energy [6] is based on the assumption that the wave functions of the two light quarks around the heavy quark in $\Lambda_c$, $\Lambda_b$ and around the antidiquark in the $\bar{c}\bar{c}qq$ and $\bar{b}\bar{b}qq$ dimesons are very similar. This assumpton implies that the heavy antidiquark in a colour triplet state acts just like a very heavy quark and that the $1/m$ corrections are neglected [7]. We show by means of a detailed calculation [8,6] that the deviations from both assumptions lead only to minor corrections.

## 2 The phenomenological relation for the binding energy of dimesons

We call the $u$ and $d$ quarks $q$ and the dimesons (tetraquarks) $(\bar{b}\bar{b}qq) = T_{bb}$, $(\bar{c}\bar{c}qq) = T_{cc}$. The masses of particles are denoted just by their names, and the tilde denotes a hyperfine average (e.g. $\tilde{D} = \frac{1}{4}D + \frac{3}{4}D^*$).

The binding energies $E_{b\bar{b}}$ of a quark and antiquark in a meson is a function of the reduced mass only, e.g. $\Upsilon = b + b + E_{b\bar{b}}$, $E_{b\bar{b}} = F(m = b/2)$. For the diquark $bb$ the Schrödinger equation is similar as for the $b\bar{b}$ meson with twice weaker interaction

$$\left[\frac{p^2}{2(b/2)} + V_{bb}\right]\psi = \tfrac{1}{2}\left[\frac{p^2}{2(b/4)} + V_{b\bar{b}}\right]\psi = E_{bb}\psi, \qquad E_{bb} = \tfrac{1}{2}F(b/4).$$

Now we compare the following hadrons (and analogous for charm)

$$T_{bb} = 2b + 2q + E_{bb} + E_{qqQ}, \qquad \Upsilon = 2b + E_{b\bar{b}}, \qquad \Lambda_b = b + 2q + E_{qqQ},$$

where $E_{qqQ} \approx E_{qq(\bar{b}\bar{b})} \approx E_{qqb}$ is the potential plus kinetic energy contribution of the two light quarks in the field of a "heavy quark". We obtain the phenomenological relations

$$T_{bb} = \Lambda_b + \tfrac{1}{2}\Upsilon + \delta E_{bb}, \qquad \delta E_{bb} = \tfrac{1}{2}[F(b/4) - F(b/2)].$$

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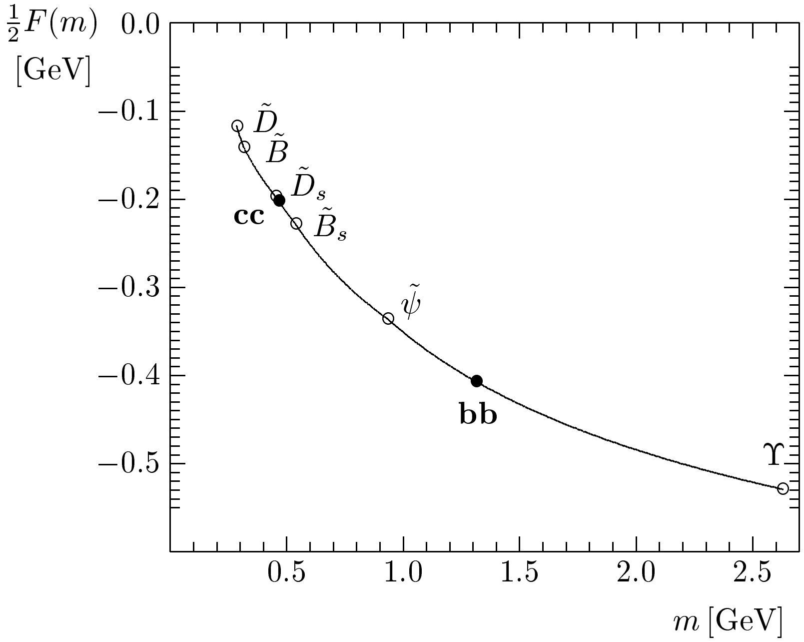
[**] E-mail: mitja.rosina@ijs.si

$$T_{cc} = \Lambda_c + \tfrac{1}{2}J/\psi + \delta E_{cc}, \qquad \delta E_{cc} = \tfrac{1}{2}[F(c/4) - F(c/2)].$$

The binding of the $(I = 0, J = 1)$ dimesons is expressed with respect to the corresponding thresholds

$$\triangle T_{bb} = \Lambda_b + \tfrac{1}{2}\Upsilon - B - B^* + \delta E_{bb} = -250\,\mathrm{MeV} + \delta E_{bb},$$
$$\triangle T_{cc} = \Lambda_c + \tfrac{1}{2}J/\psi - D - D^* + \delta E_{cc} = -42\,\mathrm{MeV} + \delta E_{cc}.$$

Now comes an important idea how to obtain phenomenologically the "corrections" $\delta E$. In Fig.(2) we interpolate between the phenomenological binding energies obtained from experimental meson masses and from a popular sets of quark masses [9], (b=5259 MeV, c=1870 MeV, s=600 MeV). The tilde denotes hyperfine averages between $0^-$ and $1^-$ states.



$$\tfrac{1}{2}F(\tfrac{1}{4}b) = -407\,\mathrm{MeV}, \qquad \delta E_{bb} = +122\,\mathrm{MeV}, \qquad \triangle T_{bb} = -128\,\mathrm{MeV}$$
$$\tfrac{1}{2}F(\tfrac{1}{4}c) \approx -197\,\mathrm{MeV}, \qquad \delta E_{cc} = +139\,\mathrm{MeV}, \qquad \triangle T_{cc} = +97\,\mathrm{MeV}.$$

These values are very close to the result $\triangle T_{bb} = -131\,\mathrm{MeV}$ (and $T_{cc}$ unbound) of a detaild 4-body calculation [4].

Now we make several corrections to our assumptions and approximations, based on detailed calculations [8,6].

**Table 1.** Corrections to the binding energy of $T_{bb} = BB^*$

| | |
|---|---|
| Spin-spin interaction | +5 MeV |
| Centre-of-mass motion | -15 MeV |
| Finite size of $\bar{b}\bar{b}$ | +18 MeV |
| Mixing of colour (6)–(6) configurations | -25 MeV |
| Total: | -17 MeV |

We have also performed a search for a two-cluster configuration ("molecule" $BB^*$). At short distance, the colour triplet configurations give a Coulomb-like attraction while the colour sextet configurations give repulsion. At intermediate distances one can gain energy with a strong mixing between triplet and sextet configurations. Detailed calculations [8] with the Born-Oppenheimer wave function (Resonating Group Method) gave no bound states with a two-cluster ("molecular" or "covalent") structure.

## 3 Conclusion

It has been hypothesized that the binding energy of heavy dimesons $B+B^*$ and $D+D^*$ might discriminate between constituent quark models using gluon-exchange or meson-exchange spin-spin interaction, or both. It was expected that models with meson-exchange interaction would give an additional strong attraction when the two light quarks meet in I+S=0 state.

The argument was wrong. The two light quarks in the dimesons feel the heavy antidiquark similarly as they feel the heavy quark in $\Lambda_b$ and $\Lambda_c$ baryons. Any interaction (OGE, OGBE or combination of both) which fits $\Lambda_b$ and $\Lambda_c$ will give similar results for dimeson binding energy and one cannot discriminate. Calculations which simply added OGBE to OGE gave strong binding of dimesons, but were irrelevant since they would overbind heavy baryons.

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