Spectra of Heavy-Light Mesons

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Abstract

We present templates for the spectra of highly excited heavy-light ($Q\bar{q}$) mesons that are derived from potential-model descriptions of quarkonium ($Q\bar{Q}$) spectra.

When we have information about the energy levels of one family of heavy-light mesons, heavy-quark symmetry is an apt tool for mapping that information onto another heavy-light family [1]. When that information is lacking for all the heavy-light families (charmed mesons and above), we must fall back upon more model-dependent considerations. It is noteworthy that the spin-independent spectra of heavy-light mesons calculated in potentials constructed to describe the ψ and Υ spectra reproduce the known general features of the heavy-light spectra, particularly along the leading Regge trajectory. The calculated energy levels define templates that may be useful in anticipating the spectroscopy and in making preliminary assignments of levels discovered in the future.

We consider two functional forms for the potential that give reasonable accounts of the $c\bar{c}$ and $b\bar{b}$ spectra: the QCD-motivated potential given by Buchmüller and Tye [2], with (constituent) quark masses

$$m_c = 1.48\ \mathrm{GeV}/c^2 \qquad m_b = 4.88\ \mathrm{GeV}/c^2$$
$$m_s = 0.45\ \mathrm{GeV}/c^2 \qquad m_u = m_d = 0.30\ \mathrm{GeV}/c^2\ ;$$

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and a Coulomb-plus-linear potential (the "Cornell potential") [3],

$$V(r) = -\frac{\kappa}{r} + \frac{r}{a^2} \ ,$$

with

$$\begin{aligned} m_c &= 1.84 \text{ GeV}/c^2 & m_b &= 5.18 \text{ GeV}/c^2 \\ m_s &= 0.45 \text{ GeV}/c^2 & m_u &= m_d = 0.32 \text{ GeV}/c^2 \\ \kappa &= 0.52 & a &= 2.34 \text{ GeV}^{-1} \ . \end{aligned}$$

We solve the Schrödinger equation, turning a blind eye to the fact that heavy-light mesons are far from nonrelativistic systems [4]. For each meson flavor, we adjust the 1S energy level to the value

$$M(1S) = \frac{3M(1^-) + M(0^-)}{4}$$

determined from experiment [5, 6]. The resulting spin-independent spectra of K, D, D_s, B, and B_s mesons are presented in Table 1 for the Buchmüller-Tye potential and in Table 2 for the Cornell potential. The essential features of the spectra are quite similar in the two potentials. We have not attempted to estimate spin splittings. The relativistic quark model of Godfrey and Isgur [7], which includes an estimate of spin splittings, gives similar predictions [8].

In the figures that follow, the Buchmüller-Tye spectra are compared with what is known experimentally [5, 6, 9]. The agreement encourages us to take the calculated energy levels as good first guesses for the positions of the unobserved levels. In addition to the 2^- and 3^- states whose properties we have predicted in [1], the first radial excitations of the D_s and B_s may be especially good candidates for discovery.

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Table 1: Masses (in GeV/c^2) of heavy-light mesons in the Buchmüller-Tye potential. The 1S center of gravity has been adjusted to match experiment.

Level	K	D	D_s	B	B_s
1S	0.7943	1.973	2.075	5.313	5.403
2P	1.312	2.460	2.538	5.790	5.854
2S	1.592	2.710	2.761	6.029	6.064
3D	1.715	2.830	2.880	6.149	6.183
3P	1.962	3.051	3.077	6.361	6.369
4F	2.066	3.149	3.172	6.457	6.462
3S	2.205	3.269	3.271	6.569	6.552

Table 2: Masses (in GeV/c^2) of heavy-light mesons in the Cornell potential. The 1S center of gravity has been adjusted to match experiment.

Level	K	D	D_s	B	B_s
1S	0.7943	1.973	2.075	5.313	5.403
2P	1.326	2.463	2.541	5.806	5.864
2S	1.636	2.732	2.781	6.064	6.088
3D	1.749	2.843	2.893	6.176	6.200
3P	2.028	3.089	3.115	6.413	6.411
4F	2.123	3.178	3.200	6.500	6.495
3S	2.299	3.325	3.326	6.640	6.612

References

[1] Estia J. Eichten, Christopher T. Hill, and Chris Quigg, *Phys. Rev. Lett.* **71**, 4116 (1993). For an update with additional details, see Estia J. Eichten, Christopher T. Hill, and Chris Quigg, "Orbitally Excited Heavy-Light Mesons Revisited," FERMILAB-CONF-94/118-T.

[2] W. Buchmüller and S.-H. H. Tye, *Phys. Rev.* D**24**, 132 (1981).

[3] E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, T.-M. Yan, *Phys. Rev.* D**17**, 3090 (1978); *ibid.* **21**, 313E (1980); *ibid.* **21**, 203 (1980).

[4] The surprising success of potential-model descriptions of the light hadrons is reviewed, for example, in W. Lucha, F. F. Schöberl, and D. Gromes, *Phys. Rep.* **200,** 127 (1991).

[5] Particle Data Group, *Phys. Rev.* D**45**, S1 (1992).

[6] Heavy-quark symmetry predicts that the center of gravity of the 1S B_s states lies 34.5 MeV/c^2 above the pseudoscalar mass, as in the B system. We take $M(B_s)$ = 5368.5 MeV/c^2, an informal average of the observed values. F. Abe, et al. (CDF Collaboration), *Phys. Rev. Lett.* **71**, 1685 (1993), report the mass of the B_s meson as 5383.3 ± 4.5 (stat.) ± 5.0 (sys.) MeV; D. Buskulic, et al. (ALEPH Collaboration), *Phys. Lett.* **B311**, 425 (1993), *ibid.* **B316**, 631E (1993), report 5368.6 ± 5.6 (stat.) ± 1.5 (sys.) MeV/c^2. P. Abreu, et al. (DELPHI Collaboration), *Phys. Lett.* **B324**, 500 (1994), report 5374 ± 16 (stat.) ± 2 (sys.) MeV/c^2. See also P. D. Acton, et al. (OPAL Collaboration), *Phys. Lett.* **B295**, 357 (1992). A preliminary value from CDF, $M(B_s)$ = 5367.7±2.4 (stat.)±4.8 (sys.) MeV/c^2, is reported in J. D. Lewis, "Mass and Lifetime Measurements with Exclusive B Reconstruction from CDF," CDF/PUB/BOTTOM/PUBLIC/2603, FERMILAB-CONF-94/128-E, to appear in the Proceedings of the 1994 Rencontre de Physique de la Vallée d'Aoste.

[7] S. Godfrey and N. Isgur, *Phys. Rev.* D**32**, 189 (1985).

[8] The validity of the quark model with a relativistic form for the kinetic energy has been investigated on the lattice by A. Duncan, E. Eichten, and H. Thacker, *Phys. Lett.* **303**, 109 (1993).

[9] The D_{s2}^{*} has been reported for the first time by Y. Kubota, et al. (CLEO Collaboration), Cornell preprint CLNS 94/1266 (unpublished), with a mass of 2573.2 ± 1.9 MeV/c^2.

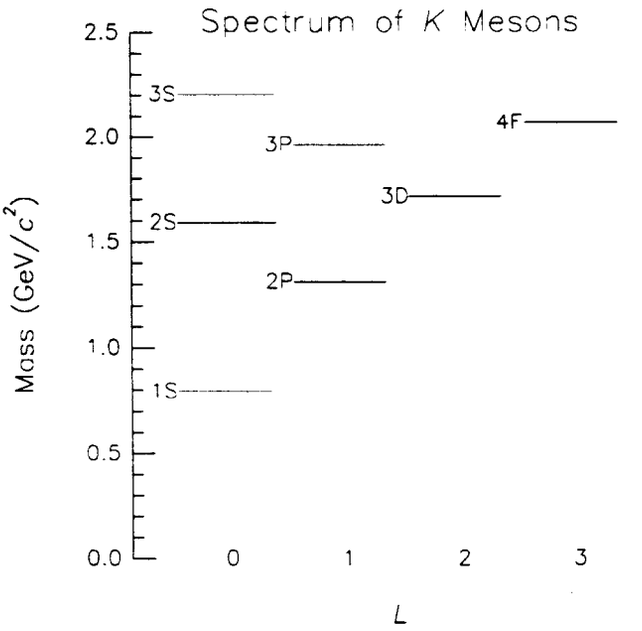

Figure 1: Spectrum of strange mesons in the Buchmüller-Tye potential.

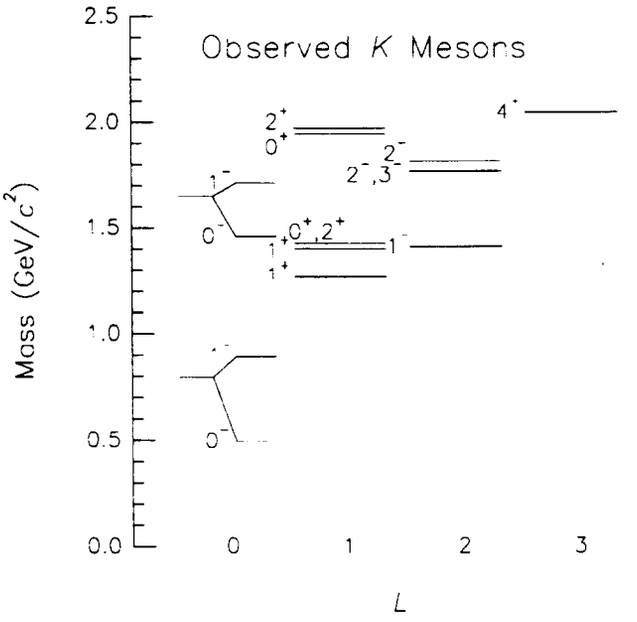

Figure 2: Spectrum of observed strange mesons.

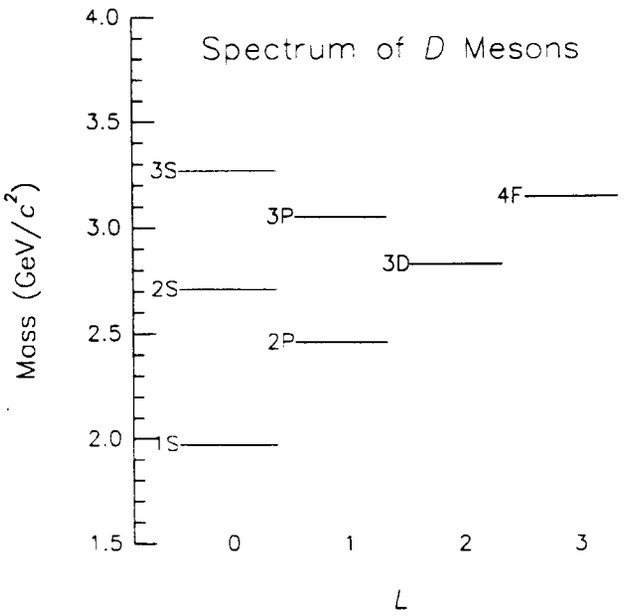

Figure 3: Spectrum of charmed mesons in the Buchmüller-Tye potential.

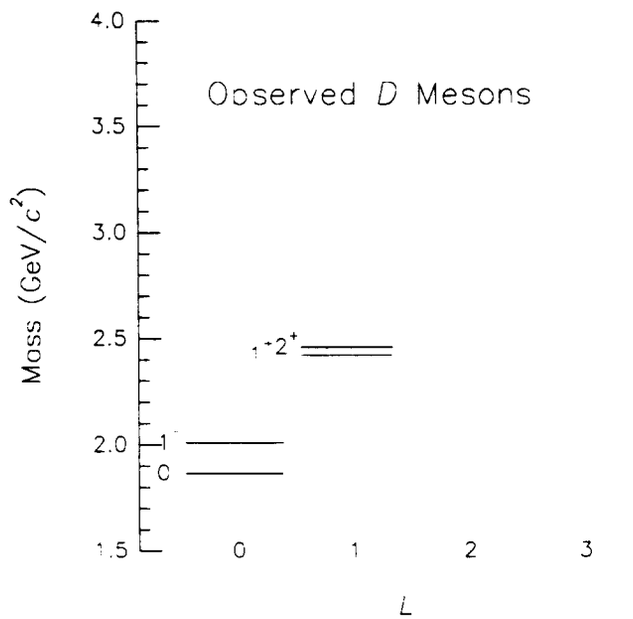

Figure 4: Spectrum of observed charmed mesons.

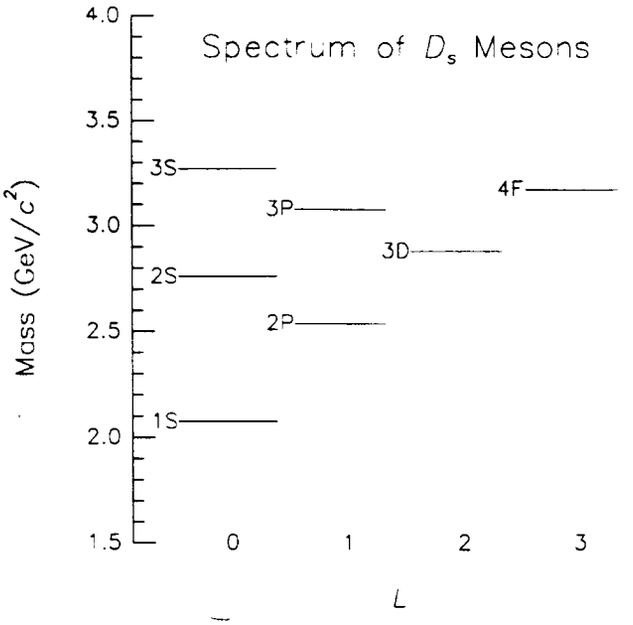

Figure 5: Spectrum of charmed-strange mesons in the Buchmüller-Tye potential.

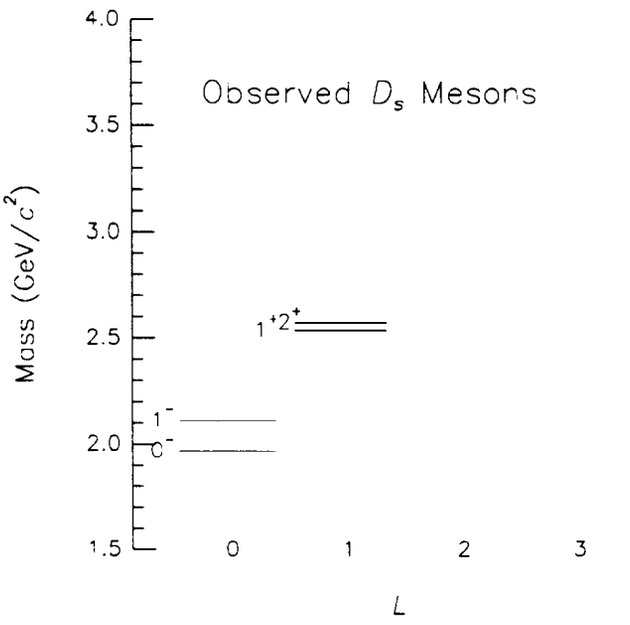

Figure 6: Spectrum of observed charmed-strange mesons.

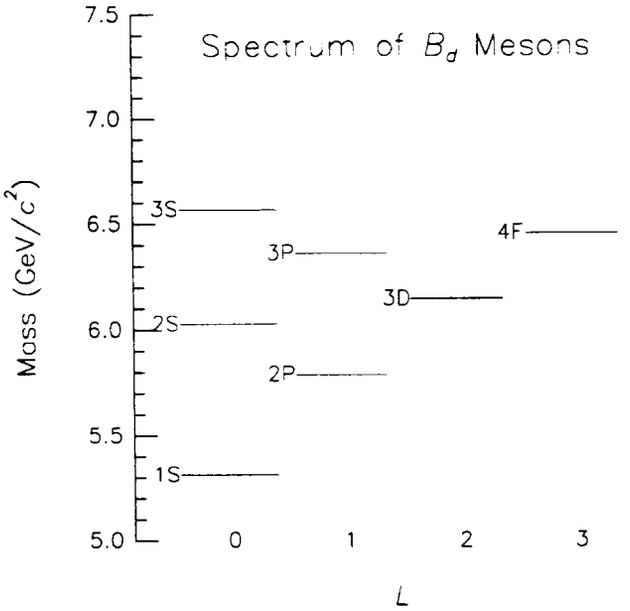

Figure 7: Spectrum of B mesons in the Buchmüller-Tye potential.

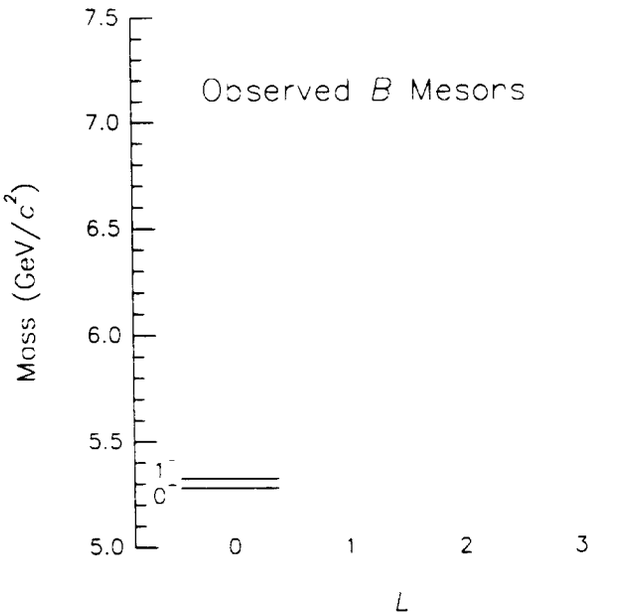

Figure 8: Spectrum of observed B mesons.

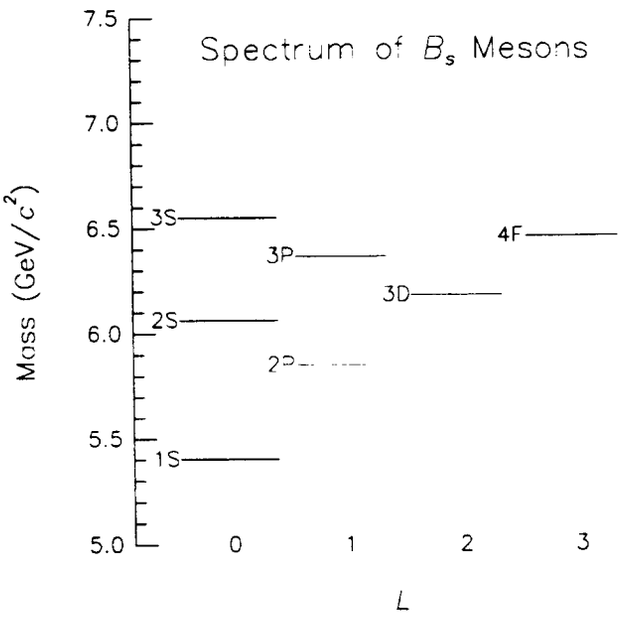

Figure 9: Spectrum of B_s mesons in the Buchmüller-Tye potential.

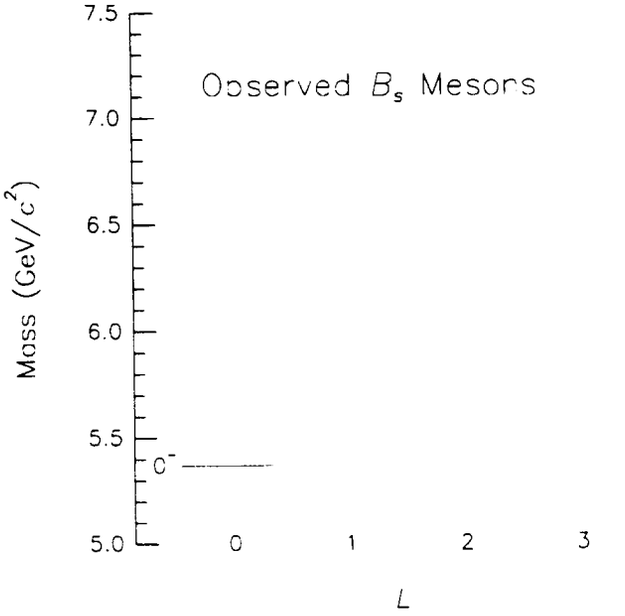

Figure 10: Spectrum of observed B_s mesons.