Comment on "Spin-Dependent Forces in Heavy-Quark Systems"

A few years ago, the $b\bar{b}$ and $c\bar{c}$ spectra were investigated by us[1] with the use of a perturbative quantum-chromodynamic potential supplemented by a scalar-exchange linear confining potential. An essential feature of our model was the inclusion of the complete one-loop radiative corrections in the perturbative part of the quark-antiquark potential, and our results have been found to be in excellent agreement with experiments.[2] Recently this problem has been reexamined by Ng, Pantaleone, and Tye.[3] Since spectroscopy of heavy quarkonia is particularly suitable for a confrontation of quantum chromodynamics with the experimental data, we shall comment on the similarities as well as the differences between our treatment and that of Ng, Pantaleone, and Tye.

QCD radiative corrections.—The Bethe-Salpeter approach has been extensively used for the treatment of bound states for many years. More recently, an alternative and simpler treatment has been developed by Gupta and Radford by deriving the two-particle potential from the scattering operator,[4] and they have used it to obtain the complete one-loop QCD radiative corrections to the quark-antiquark potential.[5]

As in our earlier treatment, Ng, Pantaleone, and Tye have included the radiative corrections, obtained by Gupta and Radford, in the perturbative potential for the quark-antiquark system.[6] They have, however, used the modified minimal-subtraction ($\overline{\rm MS}$) renormalization scheme[7] for this purpose. On the other hand, we used the Gupta-Radford (GR) renormalization scheme,[8] which is more physical because it is a simplified momentum-space subtraction scheme. Since the results in the GR and $\overline{\rm MS}$ schemes become equivalent if we set

$$\mu_{\rm GR}^2=\mu_{\overline{\rm MS}}^2\exp\left(\frac{49-10n_f/3}{33-2n_f}\right),$$

the difference between the two schemes is equivalent to a difference in the choice of the renormalization scale μ.

Determination of μ and α_s.—The choice of renormalization scale μ has been widely discussed in the literature, but there is no consensus as to which prescription is to be preferred. Ng, Pantaleone, and Tye have chosen Grunberg's prescription, in which μ is chosen so as to make the next-to-leading order coefficient vanish. We proposed and used another prescription[1] with a view to minimizing the effect of higher-order terms which would be generated by renormalization-group improvement of our potential.

Ng, Pantaleone, and Tye point out that different physical processes in general have different values of α_s, and they treat contributions to quarkonium energy levels resulting from various types of terms in the quark-antiquark potential as different physical processes. Moreover, their wave functions have been determined with the use of a potential which yields the rather large value of 300 MeV for $\Lambda_{\overline{\rm MS}}$. On the other hand, we used the same value of α_s for all potential terms, and our value of Λ agrees with the generally accepted value of this parameter.

Long-range quark-antiquark potential.—Ng, Pantaleone, and Tye have attempted to deduce the long-range spin-dependent potential with use of a general treatment, which has been applied by them to four types of potentials. They have thus arrived at the conclusion that "better data will be able to distinguish the model of short-range spin forces from the model of scalar long-range force and other models."

We have ourselves investigated several types of confining potentials during the past several years, but we found only the results obtained with a scalar-exchange linear confining potential worthy of publication.[1] It is also interesting that the spin dependence in such a confining potential appears in the form of a spin-orbit term, which plays only a minor role in the P-state splittings of $b\bar{b}$, while its effect is considerably larger for $c\bar{c}$. Considering both the $b\bar{b}$ and $c\bar{c}$ results, we believe that the confining quark-antiquark potential for heavy quarkonia behaves predominantly as a scalar-exchange linear potential.

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[6]Note that Ref. 3 contains misprints, which can be corrected with the help of the results in Refs. 5 and 1.

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