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Isospin violation in $J/\psi \to$ baryon + antibaryon

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Isospin-violating electromagnetic contributions to the decays $J/\psi \to$ baryon + antibaryon are examined. We find that these isospin-violating effects may be large, and that they depend sensitively on the magnetic form factors of the baryons.

The measured branching fractions[1] for the exclusive decays of the J/ψ into members of the baryon octet and their antiparticles are consistent with SU(3) violations that are less than 30% in the amplitudes. If these SU(3) violations are predominantly due to the strange-quark mass, then isospin violations due to quark masses are less than 1% in the amplitudes since these are suppressed by $(m_u - m_d)/m_s$ relative to the SU(3) violations.[2] In this paper we estimate the isospin violations produced by electromagnetic corrections. Our results indicate that these isospin violations may be quite large and are sensitive to the baryon magnetic form factors.

The amplitude for $J/\psi \to B\bar{B}$ may be written in terms of two form factors, i.e.,

$$A(J/\psi \to B\bar{B}) = -i\epsilon_\psi^\mu \bar{u}(p_B)\left[E^{B\bar{B}}\gamma_\mu + F^{B\bar{B}}\frac{(p_B - p_{\bar{B}})_\mu}{2m_B}\right]v(p_{\bar{B}}) , \tag{1}$$

where ϵ_ψ is the polarization vector of the J/ψ. To the extent that the J/ψ mass M_ψ is large, this amplitude is dominated by the form factor $E^{B\bar{B}}$. This form factor is the convolution[3]

$$E^{B\bar{B}} = \int_0^1 [dx][dy]\phi^*(x_i, M_\psi{}^2)T_H^{B\bar{B}}(x_i, y_i; M_\psi{}^2)\phi(y_i, M_\psi{}^2) \tag{2}$$

of a collinear hard-scattering amplitude $T_H^{B\bar{B}}$ with the amplitudes $\phi(x_i, M_\psi{}^2)$ for a baryon to consist of three quarks collinear up to scale $M_\psi{}^2$ and carrying fractions x_i of the baryon's longitudinal momentum ($[dx] = dx_1 dx_2 dx_3 \delta(1 - x_1 - x_2 - x_3)$ and $i \in \{1,2,3\}$). Isospin-violating electromagnetic corrections to the hard-scattering amplitude are suppressed by only a factor of $\alpha_e/\alpha_s(M_\psi{}^2)$ and are expected to dominate over the electromagnetic corrections to the quark distribution amplitudes.[4] We assume that ϕ is symmetric in the x_i so that the baryons have their familiar SU(6) flavor-spin structure.[3,5]

The leading contribution to $T_H^{B\bar{B}}$ arises from the strong interactions through the graphs of Fig. 1. This contribution to $T_H^{B\bar{B}}$ was evaluated in Ref. 6 with the result

$$T_{\text{strong}}^{B\bar{B}} = -\frac{80}{9\sqrt{6}}\frac{[4\pi\alpha_s(M_\psi{}^2)]^3}{M_\psi{}^6}\phi(0)\frac{x_1y_3 + x_3y_1}{x_1x_2x_3[x_1(1-y_1)+y_1(1-x_1)][x_3(1-y_3)+y_3(1-x_3)]y_1y_2y_3} . \tag{3}$$

Here $\phi(0)$ is the nonrelativistic J/ψ wave function evaluated at the origin. The SU(3)-symmetric strong-interaction contribution to the $J/\psi \to B\bar{B}$ form factor, $E_{\text{strong}}^{B\bar{B}}$, is the convolution of $T_{\text{strong}}^{B\bar{B}}$ with the quark distribution amplitudes [cf. Eq. (2)].

Isospin-violating electromagnetic corrections to the hard-scattering amplitude arise from two sources. One source consists of graphs similar to those of Fig. 1, but with one of the gluons replaced by a photon. The contribution of these graphs to $T_H^{B\bar{B}}$ is

$$-\frac{4\alpha_e Q_B}{5\alpha_s(M_\psi{}^2)}T_{\text{strong}}^{B\bar{B}} , \tag{4}$$

where Q_B is the charge of the final-state baryon. The second source of electromagnetic corrections is the diagram in Fig. 2 which yields a contribution to $T_H^{B\bar{B}}$ proportional to the hard-scattering ampli-

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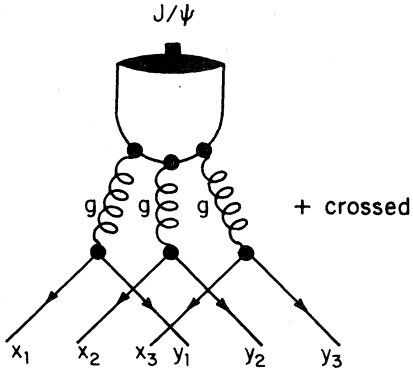

FIG. 1. SU(3)-invariant strong-interaction contribution to the hard-scattering amplitude.

tude for the baryon magnetic form factor $G_M^B(Q^2)$ at timelike $Q^2=M_\psi^2$. Convoluting these corrections to the hard-scattering amplitude with the quark distribution amplitudes gives the electromagnetic correction to the $J/\psi \to B\bar{B}$ form factor

$$E_{\text{em}}^{B\bar{B}} = -\frac{4}{5}\frac{\alpha_e}{\alpha_s(M_\psi^2)} Q_B E_{\text{strong}}^{B\bar{B}} - \frac{4}{\sqrt{6}}\frac{4\pi\alpha_e}{M_\psi^2} G_M^B(M_\psi^2)\phi(0)\ . \quad (5)$$

The measured branching fraction[7] $B(J/\psi \to p\bar{p}) = (1.8 \pm 0.2) \times 10^{-3}$ and the following expression for the rate,

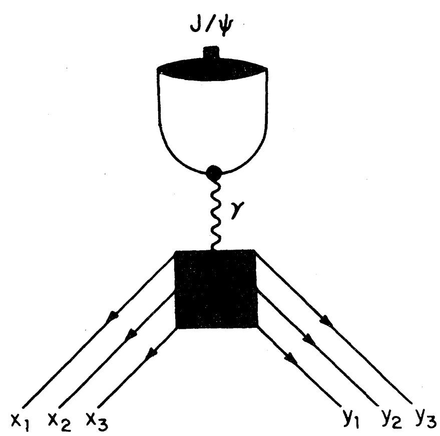

FIG. 2. Electromagnetic contribution to $T_H^{B\bar{B}}$ that is proportional to the hard-scattering amplitude for baryon magnetic form factors. The black box encompasses the strong-interaction effects.

$$\Gamma(J/\psi \to B\bar{B}) = \frac{M_\psi^2 + 2m_B^2}{6\pi}\left[1 - \frac{4m_B^2}{M_\psi^2}\right]^{1/2} |E^{B\bar{B}}|^2\ , \quad (6)$$

give $|E_{\text{strong}}^{B\bar{B}}| = 5.0 \times 10^{-4}\ (\text{GeV})^{-1/2}$, provided that $E^{B\bar{B}}$ is dominated by the strong-interaction contribution. In evaluating $E_{\text{em}}^{B\bar{B}}$ we use the values $\alpha_s(M_\psi^2) = 0.2$ and $|\phi(0)| = 0.19\ \text{GeV}^{3/2}$ determined by comparing expressions for the total hadronic width of the J/ψ,

$$\Gamma(J/\psi \to \text{hadrons}) = \tfrac{160}{81}(\pi^2 - 9)\frac{\alpha_s(M_\psi^2)^3}{M_\psi^2} |\phi(0)|^2\ , \quad (7)$$

and the rate for $J/\psi \to \mu^+\mu^-$,

$$\Gamma(J/\psi \to \mu^+\mu^-) = \frac{64\pi}{9}\frac{\alpha_e^2}{M_\psi^2} |\phi(0)|^2\ , \quad (8)$$

with their measured values. Although the hard-scattering amplitude for the baryon magnetic form factor has been computed,[3] use of this result requires knowledge of the quark distribution amplitudes. Instead, we use the measured value $G_M^p(-M_\psi^2) = 1.2 \times 10^{-2}$ for the proton magnetic form factor[8] at spacelike $Q^2 = -M_\psi^2$. To leading order in $\alpha_s(M_\psi^2)$, this value may be continued to timelike $Q^2 = M_\psi^2$. The magnetic form factors of the other baryons are not measured at such large Q^2. However, we can get some idea of their values by examining their asymptotic behavior. For example, at very large Q^2, the neutron magnetic form factor $G_M^n(Q^2)$ is negative and much greater in magnitude than $G_M^p(Q^2)$.[3] At $Q^2=0$, the nucleon magnetic moments give $G_M^n(0)/G_M^p(0) = -0.68$. In Fig. 3, the ratio of rates $\Gamma(J/\psi \to n\bar{n})/\ \Gamma(J/\psi \to p\bar{p})$ is plotted as a function of $R = -G_M^n(M_\psi^2)/G_M^p(M_\psi^2)$ for $0 \le R \le 4$. If $R > 1$, the isospin violations are very large. The measured branching ratio[1] $B(J/\psi \to n\bar{n}) = (1.8 \pm 0.9) \times 10^{-3}$ indicates that $R < 3.5$. Similar results hold for isospin violations in decays of the J/ψ into hyperon-antihyperon pairs.

We have seen that isospin violations in $J/\psi \to B\bar{B}$ may be substantial and depend sensitively on the baryon magnetic form factors. In estimating these effects, we have used a formalism which rigorously produces the leading-order contributions in $\alpha_s(Q^2)$ and Λ^2/Q^2 as $Q^2 \to \infty$ (Λ is a scale set by quark masses, transverse momenta, and nonperturbative effects). At the moderate momentum transfers involved in J/ψ decays, the correc-

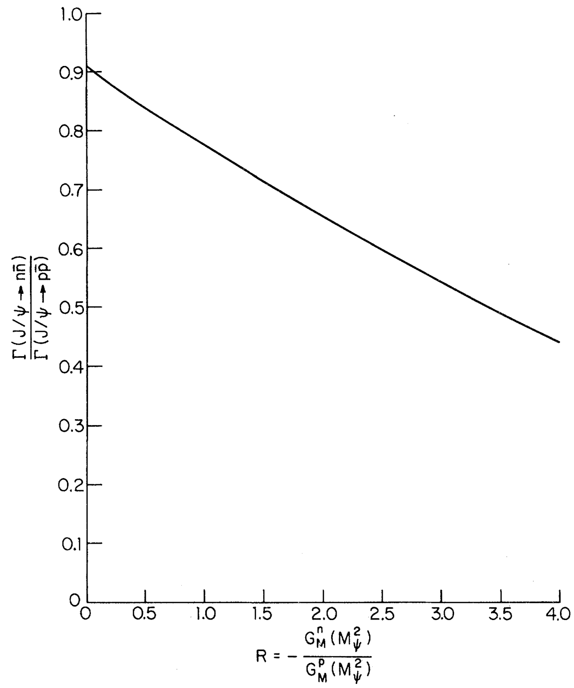

FIG. 3. Plot of $\Gamma(J/\psi \rightarrow n\bar{n})/\Gamma(J/\psi \rightarrow p\bar{p})$ versus $R = -G_M^n(M_\psi{}^2)/G_M^p(M_\psi{}^2)$.

tions may be substantial.[9] However, our reliance on this formalism is limited to justifying the suppression of $F^{B\bar{B}}$ relative to $E^{B\bar{B}}$ and to normalizing the electromagnetic corrections that are *not* related to baryon magnetic form factors. Similar results will hold in any quark-model-type estimate. An experimental indication that $E^{B\bar{B}}$ dominates the amplitude is present in the angular distribution.[6] Neglecting $F^{B\bar{B}}$,

$$\frac{d\Gamma(J/\psi \rightarrow B\bar{B})}{d(\cos\theta)} \propto 1 + \frac{M_\psi{}^2 - 4m_B{}^2}{M_\psi{}^2 + 4m_B{}^2}\cos^2\theta \ . \quad (9)$$

For $J/\psi \rightarrow p\bar{p}$ the predicted coefficient of $\cos^2\theta$ is 0.46, while the observed value[7] is 0.48 ± 0.24. A final caveat concerns the continuation of $G_M^p(Q^2)$ into the timelike region. Although nominally of order $\alpha_s(Q^2)$, the corrections may be substantial. In this regard, we note that the current experimental limit[10] on $G_M^p(M_\psi{}^2)$ in the timelike region is $G_M^p(M_\psi{}^2) \lesssim 10^{-1}$.

Note added. Work related to that in this paper can be found in Ref. 11.

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[4]Electromagnetic corrections to $\phi(x_i, M_\psi{}^2)$ either occur in loops and are thus suppressed by additional numerical factors such as $1/4\pi$ or are not enhanced by $\ln M_\psi{}^2/\Lambda^2$.
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[9]R. D. Field, R. Gupta, S. Otto, and L. Chang [University of Florida report, 1981 (unpublished)] have shown that higher-order $\alpha_s(Q^2)^2$ corrections to the pion form factor are important until the momentum transfer becomes very large. The data for $e^+e^- \rightarrow \pi^+\pi^-$ and $e^+e^- \rightarrow K^+K^-$ given in Ref. 7 seem to support this result.
[10]We use data in Ref. 7 and assume that $F_2^p(Q^2)$ is negligible. This data is taken off resonance at $Q^2 = 14.2$ GeV^2 and we extrapolate back to $Q^2 = M_\psi{}^2 = 9.6$ GeV^2 by assuming that $G_M^p(Q^2) \propto 1/Q^4$. Of course, by $G_M^p(M_\psi{}^2)$ we mean the magnetic form factor excluding contributions from the virtual J/ψ resonance.
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