Charmonium absorption in the meson-exchange model *

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We review the meson-exchange model for charmonium absorption by hadrons. This includes the construction of the interaction Lagrangians, the determination of the coupling constants, the introduction of form factors, and the predicted cross sections for $J/\psi$ absorption by both mesons and nucleons. We further discuss the effects due to anomalous parity interactions, uncertainties in form factors, constraints from chiral symmetry, and the change of charmed meson mass in medium on the cross sections for charmonium absorption in hadronic matter.

1. INTRODUCTION

Suppression of charmonium production in high energy heavy ion collisions is one of the most discussed possible signals for the quark-gluon plasma (QGP) that is expected to be formed in these collisions \cite{1}. Recent data from the Pb+Pb collision at $R_{\text{lab}} = 158$ GeV/c in the NA50 experiment at CERN-SPS \cite{2} have indeed shown an anomalously large $J/\psi$ suppression in events with moderate to large transverse energy. Although this anomalous suppression may very likely be due to the formation of the QGP \cite{3}, the conventional mechanism based on $J/\psi$ absorption by comoving hadrons has also been shown to contribute significantly to the observed suppression if the absorption cross sections are taken to be a few mb \cite{4}. For heavy ion collisions at RHIC where the number of charm mesons per event increases appreciably from SPS, these hadronic processes and their inverse reactions may even lead to a net production of $J/\psi$ during the hadronic stage of the collisions \cite{5}.

Since there is no empirical information on the cross sections for charmonium absorption by light hadrons, theoretical models are needed to determine their values. These include the perturbative QCD method, the quark-interchange model, and the meson-exchange model. In the perturbative QCD approach \cite{6}, charmonia are dissociated by the gluons from the colliding light hadron. The predicted $J/\psi$ dissociation cross section is found to increase monotonously with the kinetic energy $E_{\text{kin}} \equiv \sqrt{s} - m_h - m_\psi$ but has a value of only about 0.1 mb at $E_{\text{kin}} \sim 0.8$ GeV. In the quark-interchange model, both the charmonium and the light hadron are treated as composites of constituent quarks, and the absorption of charmonium is via the interchange of the charm quark in the charmonium with the light quark in the light hadron. An earlier study \cite{7} based on this model gives a $J/\psi$ absorption cross section by pion that has a peak value of about 7 mb at the kinetic energy of $\simeq 0.8$

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GeV. Later studies predict, however, a peak value of only \( \sim 1 \text{ mb} \) at the same kinetic energy. In both cases, the cross sections are much greater than that obtained from the perturbative QCD method.

In the meson-exchange model, the cross sections between charmonia and hadrons are evaluated using effective hadronic Lagrangians derived from the SU(4) flavor symmetry. In the first application of this model, only interaction Lagrangians involving pseudoscalar-pseudoscalar-vector-meson couplings are included [9]. Without employing form factors at the interaction vertices, the resulting cross section for \( J/\psi \) absorption by pion is about 0.3 mb at the kinetic energy of 0.8 GeV. In later more complete studies, both three-vector-meson and four-point couplings are also included [10,11,12,13,14], and much larger cross sections are obtained for \( J/\psi \) absorption by light hadrons. In contrast to the perturbative QCD approach and the quark-interchange model, form factors are needed at the interaction vertices in the meson-exchange model to take into account the finite size of hadrons. The cross sections for \( J/\psi \) absorption by light hadrons depend sensitively on the form factors. Although there are some studies of the form factors involving charmed hadrons [15], the monopole form factors with cutoff parameters of about 1 GeV have been used in most meson-exchange model calculations. The resulting cross sections are a few mb, which are somewhat larger than those from the perturbative QCD method.

In the following, we shall review in more detail the meson-exchange model and its predictions on the cross sections for \( J/\psi \) absorption by hadrons. We shall also discuss the effects due to anomalous parity interactions, uncertainties in form factors, constraints from chiral symmetry, and the change of charmed meson mass in medium.

2. THE MESON-EXCHANGE MODEL

2.1. The effective Lagrangian

To obtain the interaction Lagrangians for charmonia and charmed mesons with the least number of free parameters, we start with the free Lagrangian for pseudoscalar and vector mesons in the SU(4) limit, i.e.,

\[
L_0 = \text{Tr} \left( \partial_\mu P^\dagger \partial^\mu P \right) - \frac{1}{2} \text{Tr} \left( F^\dagger_{\mu\nu} F^{\mu\nu} \right),
\]

(1)

where \( F_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu \), and \( P \) and \( V \) denote, respectively, the properly normalized \( 4 \times 4 \) pseudoscalar and vector meson matrices in SU(4) [4,10]:

\[
P = \frac{1}{\sqrt{2}} \begin{pmatrix}
\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} + \frac{\eta_c}{\sqrt{12}} & \pi^- & \pi^+ & K^+ & \bar{D}^0 \\
\pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} + \frac{\eta_c}{\sqrt{12}} & \eta & K^0 & D^- \\
\pi^+ & \eta & K^- & \bar{K}^0 & \bar{D}^0 \\
K^- & \bar{K}^0 & D^0 & \frac{1}{\sqrt{6}} \eta + \frac{\eta_c}{\sqrt{12}} & D_s^- \\
\bar{D}^0 & \bar{D}^0 & D_s^0 & -\frac{3}{\sqrt{2}} \eta + \frac{3\eta_c}{\sqrt{12}} \\
\end{pmatrix},
\]

\[
V = \frac{1}{\sqrt{2}} \begin{pmatrix}
\frac{\rho^0}{\sqrt{2}} + \frac{\omega^0}{\sqrt{6}} + \frac{J/\psi}{\sqrt{12}} & \rho^- & \rho^+ & K^{*+} & \bar{D}^{*0} \\
\rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega^0}{\sqrt{6}} + \frac{J/\psi}{\sqrt{12}} & \omega^+ & K^{*0} & D^{*-} \\
\rho^+ & \omega^+ & K^{*-} & \bar{K}^{*0} & \bar{D}^{*0} \\
K^{*-} & \bar{K}^{*0} & D^{*0} & \frac{1}{\sqrt{6}} \omega^0 + \frac{J/\psi}{\sqrt{12}} & D_s^{*-} \\
D^{*0} & D^{*0} & D_s^{*0} & -\frac{3}{\sqrt{2}} \omega^0 + \frac{3J/\psi}{\sqrt{12}} \\
\end{pmatrix}. \]

(2)
The effective Lagrangian is then given by
\[ \pi \psi \] cross section as the process \( \pi \psi \) \( M \) \( \frac{d^2 \sigma}{d^2 p} = \left| \mathcal{M} \right|^2 \), \( F_{\mu \nu} \to \partial_\mu V_\nu - \partial_\nu V_\mu - i g \frac{2}{2} [V_\mu, V_\nu] \). (3)

The effective Lagrangian is then given by
\[ \mathcal{L} = \mathcal{L}_0 + i g \text{Tr} \left( \partial^\mu P \left[ P^\dagger, V_\mu^\dagger \right] + \partial^\mu P^\dagger \left[ P, V_\mu \right] \right) - \frac{g^2}{4} \text{Tr} \left( \left[ P^\dagger, V_\mu^\dagger \right] \left[ P, V_\mu \right] \right) \]
\[ + \frac{i g}{2} \text{Tr} \left( \partial^\mu V_\mu \left[ V_\mu^\dagger, V_\nu^\dagger \right] + \partial_\mu V_\nu^\dagger \left[ V_\nu^\dagger, V_\nu \right] \right) + \frac{g^2}{8} \text{Tr} \left( \left[ V_\mu, V_\nu \right] \left[ V_\mu^\dagger, V_\nu^\dagger \right] \right). \] (4)

Hermiticity of \( P \) and \( V \) reduces the above Lagrangian to
\[ \mathcal{L} = \mathcal{L}_0 + i g \text{Tr} \left( \partial^\mu P \left[ P, V_\mu \right] \right) - \frac{g^2}{4} \text{Tr} \left( \left[ P, V_\mu \right]^2 \right) \]
\[ + i g \text{Tr} \left( \partial^\mu V_\mu \left[ V_\mu, V_\nu \right] \right) + \frac{g^2}{8} \text{Tr} \left( \left[ V_\mu, V_\nu \right]^2 \right). \] (5)

Since the SU(4) symmetry is explicitly broken by hadron masses, terms involving hadron masses are added to Eq. (3) using the experimentally determined values. The above effective Lagrangian can also be derived from the chiral Lagrangian, which includes both vector and axial vector fields, with the axial vector fields removed by gauge transformations [12,14].

With this effective Lagrangian, various reactions involving charmed mesons and \( J/\psi \) have been studied. These include charmed meson scattering such as \( \pi D \leftrightarrow \rho D^{*} \), and charmonium absorption such as \( \pi \psi \to D D^{*} \). Extension of the effective hadronic Lagrangian to SU(5) flavor symmetry allows one to study also \( \Upsilon \) absorption by hadrons [15].

For \( J/\psi \) absorption by \( \pi \) and \( \rho \) mesons, there are following processes:
\[ \pi \psi \to D^* \bar{D}, \pi \psi \to D \bar{D}^*, \rho \psi \to D \bar{D}, \rho \psi \to D^* \bar{D}^*. \] (6)

Their diagrams are shown in Figure 1 except the process \( \pi \psi \to D \bar{D}^* \) which has the same cross section as the process \( \pi \psi \to D^* \bar{D} \).

As an example, we consider explicitly the first process \( \pi \psi \to D^* \bar{D} \). Its full amplitude, without isospin factors and before summing and averaging over external spins, is given by
\[ \mathcal{M}_1 = \sum_{i=a,b,c} \mathcal{M}_{i \lambda} \epsilon_{2\nu} \epsilon_{3\lambda} \]
[7]
with
\[ \mathcal{M}_{i \alpha}^{\nu \lambda} = -g_{\pi D D^{*}} g_{\psi D D} \left( -2p_1 + p_3 \right)^\lambda \left( \frac{1}{t - m^2_D} \right) \left( p_1 - p_3 + p_4 \right)^\nu, \]
\[ \mathcal{M}_{i \lambda}^{\nu \alpha} = g_{\pi D D^{*}} g_{\psi D^* D} \left( -p_1 - p_4 \right)^\alpha \left( \frac{1}{u - m^2_{D^{*}}} \right) \left[ g_{\alpha \beta} - \left( p_1 - p_4 \right) \left( p_1 - p_4 \right)^\beta \right] \]
\[ \times \left[ \left( -p_2 - p_3 \right)^\beta g^{\nu \lambda} + \left( -p_1 + p_2 + p_4 \right)^\lambda g^{\beta \nu} + \left( p_1 + p_3 - p_4 \right)^\nu g^{\beta \lambda} \right], \]
\[ \mathcal{M}_{i \lambda}^{\nu \nu} = -g_{\pi \psi D D^{*}} g^{\nu \lambda}. \] (8)
In the above, $p_j$ denotes the momentum of particle $j$, with particles 1 and 2 representing initial-state mesons while particles 3 and 4 representing final-state mesons on the left and right sides of the diagrams shown in Figure 1, respectively. The indices $\mu$, $\nu$, $\lambda$, and $\omega$ denote the polarization components of external particles while the indices $\alpha$ and $\beta$ denote those of the exchanged mesons.

After averaging (summing) over initial (final) spins and including isospin factors, the cross section is given by

$$
\frac{d\sigma_1}{dt} = \frac{1}{96\pi s p_{t,\text{cm}}^2} \mathcal{M}_1^{\nu\lambda} \mathcal{M}_1^{\nu'\lambda'} \left( g_{\nu\nu'} - \frac{p_{2\nu} p_{2\nu'}}{m_2^2} \right) \left( g_{\lambda\lambda'} - \frac{p_{3\lambda} p_{3\lambda'}}{m_3^2} \right),
$$

with $s = (p_1 + p_2)^2$ and $p_{t,\text{cm}}$ the momentum of initial-state mesons in the center-of-mass (c.m.) frame.

### 2.2. Current conservation

The effective Lagrangian in Eq. (3) is generated by minimal substitution and is thus equivalent to treating vector mesons as gauge particles. Both $VVV$ and four-point couplings in the Lagrangian are thus due to the gauge invariance [10]. The gauge invariance also leads to current conservation conditions on the scattering amplitudes [10,11,17]. In the limit of zero vector meson masses, degenerate pseudoscalar meson masses, and SU(4) invariant coupling constants, these conditions are

$$
\mathcal{M}_n^{\lambda_k...\lambda_l} p_j \lambda_j = 0,
$$

with the index $\lambda_j$ denoting the external vector meson $j$ in the process $n$ shown in Figure 1. For example, we have $\mathcal{M}_1^{\nu\lambda} p_{3\lambda} = 0$ and $\mathcal{M}_3^{\nu\lambda\lambda'} p_{2\nu} = 0$. 

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**Figure 1.** Diagrams for $J/\psi$ absorption by pion and rho meson: 1) $\pi \psi \rightarrow D^* \bar{D}$; 2) $\rho \psi \rightarrow DD$; and 3) $\rho \psi \rightarrow D^* \bar{D}^*$. Diagrams for the process $\pi \psi \rightarrow D \bar{D}^*$ are similar to (1a)-(1c) but with each particle replaced by its antiparticle.
If the external vector meson is a member of the diagonal elements in the vector meson matrix $V$ in Eq. (2), such as the rho meson and $J/\psi$, the above current conservation condition is valid even for arbitrary hadron masses and coupling constants, reflecting the flavor conservation in strong interactions.

### 2.3. Coupling constants

In all studies based on the meson-exchange model, the coupling constants in the effective Lagrangian are determined as much as possible from the empirical information. For example, the coupling constant $g_{\pi DD^*}$ is determined from the $D^*$ decay width, given by

$$
\Gamma_{D^*\rightarrow\pi D} = g_{\pi DD^*}^2 p_f^3 / (2\pi m_{D^*}^2),
$$

where $p_f$ is the momentum of final particles in the rest frame of $D^*$. The recently measured width of $\sim 96$ keV from the CLEO experiment \[19\] then gives $g_{\pi DD^*} = 5.6$. However, an old value of $g_{\pi DD^*} = 4.4$ \[9\] has been used in most studies. For other three-point coupling constants involving the rho meson or $J/\psi$, the vector meson dominance model has been used to relate them to the fine structure constant, i.e.,

$$
\frac{\gamma_V g_{\omega DD}}{m_{\omega}} = \frac{2}{3} e, \quad \frac{\gamma_{\rho} g_{\rho DD}}{m_{\rho}^2} + \frac{\gamma_{\omega} g_{\omega DD}}{m_{\omega}^2} = \frac{1}{3} e, \quad -\frac{\gamma_{\rho} g_{\rho DD}}{m_{\rho}^2} + \frac{\gamma_{\omega} g_{\omega DD}}{m_{\omega}^2} = -\frac{2}{3} e,
$$

(11)

where $\gamma_V$ is related to the vector meson partial decay width to $e^+e^-$, i.e., $\Gamma_{Vee} = \alpha \gamma_V^2 / (3m_{V}^3)$. These relations then give

$$
g_{\rho DD} = g_{\rho DD^*} = 2.52, \quad g_{\psi DD} = g_{\psi DD^*} = 7.64.
$$

(12)

Since there is no empirical information on the four-point coupling constants, relations derived from the $SU(4)$ symmetry are thus used to determine their values in terms of the three-point coupling constants, i.e.,

$$
g_{\pi\psi DD^*} = g_{\pi DD^*} g_{\psi DD}, \quad g_{\rho\psi DD} = 2 g_{\rho DD} g_{\psi DD}, \quad g_{\rho\psi DD^*} = g_{\rho DD^*} g_{\psi DD^*}.
$$

(13)

### 2.4. Form factors

To take into account the composite nature of hadrons, form factors are needed at interaction vertices. In most studies, the form factors are taken to have the usual monopole form at the three-point $t$ channel and $u$ channel vertices, i.e.,

$$
f_3 = \frac{\Lambda^2}{\Lambda^2 + q^2},
$$

(14)

where $\Lambda$ is a cutoff parameter, and $q^2$ is the squared three momentum transfer in the c.m. frame.

The form factor at four-point vertices is less known. In Ref. \[11\] and later in some other studies, it was taken to have the form

$$
f_4 = \left( \frac{\Lambda_1^2}{\Lambda_1^2 + q^2} \right) \left( \frac{\Lambda_2^2}{\Lambda_2^2 + q^2} \right).
$$

(15)

In the above, $\Lambda_1$ and $\Lambda_2$ are the two different cutoff parameters at the three-point vertices present in the process with the same initial and final particles, and $q^2$ is the average value of the squared three momentum transfers in $t$ and $u$ channels.
For simplicity, the same value has usually been used for all cutoff parameters, i.e.,

\[ \Lambda_{\pi DD^*} = \Lambda_{\rho DD} = \Lambda_{\rho D^*D^*} = \Lambda_{\psi DD} = \Lambda_{\psi D^*D^*} \equiv \Lambda, \]

and \( \Lambda \) is chosen as either 1 or 2 GeV to study the uncertainties of the resulting cross sections due to form factors.

2.5. Cross sections for charmonium absorption

Figure 2 shows the cross sections for \( J/\psi \) absorption by pion and rho mesons as functions of the c.m. energy \( \sqrt{s} \). The cross section \( \sigma_{\pi \psi} \) includes contributions from both \( \pi \psi \to D\bar{D}^* \) and \( \pi \psi \to D^*\bar{D} \), which have same cross sections. Solid curves are the results obtained without form factors. The three \( J/\psi \) absorption cross sections are seen to have very different energy dependence near the threshold energy. While \( \sigma_{\pi \psi} \) increases monotonously with c.m. energy, the cross section for the process \( \rho \psi \to D\bar{D} \) decreases rapidly with c.m. energy, and that for the process \( \rho \psi \to D^*\bar{D}^* \) changes little with c.m. energy after an initial rapid increase near the threshold.

The results with form factors are shown by the short- and long-dashed curves for cutoff parameters \( \Lambda = 2 \) and 1 GeV, respectively. It is seen that form factors suppress strongly the cross sections and thus cause large uncertainties in their values. However, the absorption cross sections for \( J/\psi \) remain appreciable after including form factors at interaction vertices. With \( \Lambda = 1 \) GeV, the values for \( \sigma_{\pi \psi} \) and \( \sigma_{\rho \psi} \) are roughly 3 mb and 2 mb, respectively, and are comparable to those used in phenomenological studies of \( J/\psi \) absorption by comoving hadrons in relativistic heavy ion collisions [4].
3. DISCUSSIONS

3.1. Anomalous parity interactions

There are also anomalous parity interactions which contribute to $J/\psi$ absorption by light hadrons [13]. These interactions can be introduced via a gauged Weiss-Zumino term in the interaction Lagrangian, and lead to interaction Lagrangians of the $PVV$, $PPPV$, and $PVVV$ types such as $\pi D^* D^*$, $\rho DD^*$, $DD^* \psi$, $\pi D^* D^* \psi$, and $\rho DD^* \psi$. As examples, we show a few in the following:

$$\mathcal{L}_{\pi D^* D^*} = -g_{\pi D^* D^*} \epsilon^{\mu \nu \alpha \beta} \partial_\mu D_\nu^* \pi \partial_\alpha \bar{D}_\beta^*,$$
$$\mathcal{L}_{\pi DD^* \psi} = -ig_{\pi DD^* \psi} \epsilon^{\mu \nu \alpha \beta} \psi_\mu \partial_\nu D_\alpha \pi \partial_\beta \bar{D},$$
$$\mathcal{L}_{\pi D^* D^* \psi} = -ig_{\pi D^* D^* \psi} \epsilon^{\mu \nu \alpha \beta} \psi_\mu \partial_\nu D_\alpha \pi \partial_\beta \bar{D} - ih_{\pi D^* D^* \psi} \epsilon^{\mu \nu \alpha \beta} \partial_\mu \psi_\nu D_\alpha^* \pi \bar{D}_\beta^*, \quad (17)$$

where $\epsilon^{\mu \nu \alpha \beta}$ is the totally antisymmetric tensor with $\epsilon_{0123} = 1$.

As for the coupling constants in the normal interactions, the coupling constants in the anomalous parity interaction Lagrangians can mostly be determined from the vector dominance model and the SU(4) symmetry relations. The coupling constant for $\pi D^* D^*$ can, on the other hand, be related to the $\pi DD^*$ by the heavy quark spin symmetry, i.e., $g_{\pi D^* D^*} \sim \bar{M}(D) g_{\pi DD^*} / 2$ with $\bar{M}(D)$ being the average mass of $D$ and $D^*$.

The anomalous parity interactions give rise to many additional diagrams for $J/\psi$ absorption. As a result, the cross section for absorption by pion is increased by 50% although that by rho meson is not much affected [13]. They also open up new absorption processes involving $\eta_c$ and/or $b_1(1235)$ in the final state, i.e., $\pi \psi \rightarrow \eta_c \rho$ and $\pi \psi \rightarrow \eta_c b_1$ via $\omega$ exchange [12]. The coupling constant $g_{\psi \eta_c \omega}$ needed for evaluating these reactions can again be determined from the vector dominance model, and the cross sections are found to be comparable with those processes with charmed mesons in the final state.

3.2. Nuclear absorption

Since the $J/\psi$ absorption cross sections by pion and rho meson cannot be directly measured, it is useful to find empirical information which can constrain their values. One such constraint is the $J/\psi$ absorption cross section by a nucleon, as this process can be viewed as the absorption of $J/\psi$ by the virtual pion and rho meson cloud of the nucleon [20,21]. From $J/\psi$ production in photon- and proton-nucleus reactions, the extracted cross section for $J/\psi$ absorption by a nucleon is a few mb [22].

Although the total $J/\psi$ absorption cross section by a nucleon is dominated by the process $J/\psi N \rightarrow D^* \Lambda_c$ at low c.m. energies through charmed meson exchange, the process $J/\psi N \rightarrow D^* \bar{D} N$ and $J/\psi N \rightarrow D^* \bar{D} N$ due to the virtual pion and rho meson cloud of the nucleon is most important at high c.m. energies [21]. With a cutoff parameter of $\Lambda = 1$ GeV, the total $J/\psi$ absorption cross section is at most 5 mb and is consistent with the empirical value. This result thus indicates that the cross sections for $J/\psi$ absorption by pion and rho meson evaluated in previous studies using the meson-exchange model are not in contradiction with the empirical cross section for $J/\psi$ absorption by a nucleon.

3.3. Medium effects

Since $J/\psi$ absorption by comovers is important in hot and dense hadronic matter, medium effects on the charmed meson mass can affect its cross sections. At finite temperature, lattice gauge calculations have indicated that the linearly rising potential between
heavy quarks in free space changes to a saturated one as a result of the formation of a $Qq - Q\bar{q}$ pair when their separation becomes large \[23\]. This may be interpreted as the reduction of the charmed meson mass at finite temperature \[24,25\]. Although there is no lattice gauge result on the heavy quark potential at finite baryon density, explicit calculations based on the QCD sum rules analysis \[26,27\] and the quark-meson coupling model \[28\] have shown that the charmed meson mass is also reduced at finite density. With reduced charmed meson mass, not only the threshold for $J/\psi$ absorption by co-movers is reduced but also the cross sections for these reactions are enhanced \[20\]. It is thus important to take into account these medium effects in studying $J/\psi$ production and suppression in relativistic heavy ion collisions.

3.4. More on form factors

Form factors involving charm mesons introduce significant uncertainties in the predicted $J/\psi$ absorption cross sections from the meson-exchange model. One can get some information on form factors from the QCD sum rules. Recent studies based on the three point function approach \[15\] show that the $\pi DD^*$ form factor for an off-shell pion can be fitted by a Gaussian form in the pion four momentum with a range or cutoff parameter $\Lambda_\pi = 1.2$ GeV, while that for an off-shell $D$ meson is best fitted with a monopole form in the charmed meson four momentum with a cut-off parameter $\Lambda_D = 3.5$ GeV. Since $\Lambda_D$ is related to $\Lambda$ introduced in Section 2.4 by $\Lambda^2 = \Lambda_D^2 - m_D^2$. This gives $\Lambda \sim 3$ GeV, which is in the range of values used for evaluating the $J/\psi$ absorption cross sections.

Form factors that takes into account the quark substructure of the interaction vertices have also been considered \[14\]. In this scenario, a three-point interaction vertex is viewed as a quark triangle diagram and is associated with a form factor that involves the product of three Gaussian wave functions with range parameters given by the meson masses. A four-point interaction vertex is, on the other hand, viewed as a quark box diagram, and the associated form factor is a product of four Gaussian wave function with range parameters given again by the masses of the on-shell mesons. As a result, the meson-exchange diagrams are suppressed compared to the contact interaction diagrams as they involve six Gaussian factors. The resulting cross sections with these quark-model inspired form factors are thus smaller than those obtained with the monopole form factors and are comparable to those given by the quark-interchange model.

Other types of form factors, ranging from the power law form to the Gaussian form, have also been used by other groups \[14,29\]. Those results show that the different form factors also affect strongly the energy dependence of the $J/\psi$ absorption cross section. One can even adjust the form factors to obtain a cross section which is very close to that from the quark-interchange model in both its magnitude and dependence on the c.m. energy \[8\].

In most calculations, the introduction of form factors has led to violation of the current conservation conditions. It is possible to recover these conditions by introducing more general four-point interactions that involve not only the $g_{\mu\nu}$ form but also all possible lowest-order Lorentz invariant products of the external momenta \[30\]. The coefficients in these new amplitudes are then adjusted to ensure that the current conservation conditions are satisfied.
3.5. Chiral symmetry

Although the effective Lagrangian shown in Eq. (3) can be derived from the SU(4) chiral Lagrangian, it involves non-derivative couplings for pions and thus leads to finite scattering amplitudes when the external pion four momentum is zero. This violation of the soft pion theorem is a result of treating charmed mesons on the same footing as pions. To ensure the SU(2) × SU(2) chiral symmetry, the $J/\psi$ absorption cross section by pion has been evaluated in Ref. [31] by dropping those terms in the Lagrangian that involve non-derivative pion couplings. The resulting cross section is found to be reduced appreciably. A more consistent way of including chiral symmetry in the meson-exchange model is thus needed.

Also, vector mesons are treated as gauge particles in the meson-exchange model to generate their interactions. Since the SU(4) symmetry is badly broken by the heavy quark mass, it is not clear to what extent charmonia can be treated as gauge particles. An alternative approach [32] based on both chiral symmetry and heavy quark effective theory may provide a more consistent model for the interactions of charmonia with light hadrons.

4. SUMMARY

In summary, we have reviewed the study of $J/\psi$ absorption cross sections by $\pi$ and $\rho$ mesons based on the meson-exchange model. The effective hadronic Lagrangian is generated from the free Lagrangian by assuming the SU(4) flavor symmetry and treating vector mesons as gauged particle. Using coupling constants determined either empirically or from relations derived from the SU(4) symmetry, the resulting cross sections are found to be a few mb if form factors with reasonable cutoff parameters are introduced at interaction vertices. These cross sections are comparable to those from the quark-interchange model but are much greater than those from the perturbative QCD approach. They are also consistent with that extracted from $J/\psi$ production in photo- and proton-nucleus reactions as the latter can be viewed as $J/\psi$ absorption by the virtual pion and rho meson cloud of the nucleon. We have also discussed the additional contributions from the anomalous parity interactions and other anomalous processes involving $\eta_c$ in the final state. Medium effects due to reduced charmed meson mass are mentioned as they not only reduce the threshold of absorption processes but also increase their cross sections. We have further described the attempt of imposing chiral symmetry on pions by dropping the non-derivative pion couplings in the Lagrangian, which reduces appreciably the cross section for $J/\psi$ absorption by pions. Finally, we have pointed out the need to develop an improved approach based on the chiral symmetry for light hadrons and the heavy quark symmetry for heavy hadrons.

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