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Exotic resonances due to η exchange

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Abstract

The meson $X(3872)$ and several related states appear to be in large part hadronic molecules in which a heavy flavored meson (e.g., D^0) is bound to another heavy meson (e.g., $\bar{D}^{*0}$). Although not the only contribution to the binding, pion exchange seems to play a crucial role in generating the longest-range force between constituents. Mesons without u and d light quarks (such as D_s) cannot exchange pions, but under suitable conditions can bind as a result of η exchange. Channels in which this mechanism is possible are identified, and suggestions are made for searches for the corresponding molecular states, including a manifestly exotic baryonic $\Lambda_c \bar{D}_s^*$ resonance decaying into $J/\psi\,\Lambda$.
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The discovery more than a dozen years ago of a very narrow resonance, $X(3872)$ [1], right at the $D\bar{D}^*$ threshold, inaugurated a flurry of observations of charmonium-like and bottomonium-like resonances similarly correlated with thresholds. A number of these could be identified as possessing a significant "molecular" component, in which a heavy charmed or bottom hadron was bound to an anticharmed or anti-bottom hadron [2,3]. When these hadrons possess light quarks, the longest-range force between them is single-pion exchange, in analogy with the

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Table 1
Possible S-wave resonances with two D_s mesons below 4.8 GeV. Only those states with $C = +$, permitted to couple to $J/\psi\,\phi$, are shown. Here $\Delta M \equiv M - M(J/\psi) - M(\phi)$. Exchanges are labeled "d" for direct ($A\bar{B} \to A\bar{B}$) and "x" for exchange ($A\bar{B} \to B\bar{A}$). "Rank" denotes anticipated ease of detection (see text). Allowed J^P values and rank are only shown for those states which can bind via η exchange.

States (J^P)	M (MeV)	ΔM (MeV)	Binding		Allowed J^P	Rank
			by η?	by $f_0(980)$?		
$D_s^+(0^-)\ D_s^-(0^-)$	3936.6	−179.8	No	d	–	–
$D_s^+(0^-)\ D_s^{*-}(1^-)$	4080.4	−36.0	x	d	1^+	1
$D_s^{*+}(1^-)\ D_s^{*-}(1^-)$	4224.2	107.8	d	d	$0^+, 2^+$ [a]	2
$D_s^+(0^-)\ D_{s0}^{*-}(2317)(0^+)$	4286.0	169.6	x	d	0^-	2
$D_s^+(0^-)\ D_{s1}^-(2460)(1^+)$	4427.8	311.4	No [b]	d, x	$[1^-]$ [b]	2
$D_s^{*+}(1^-)\ D_{s0}^{*-}(2317)(0^+)$	4429.8	313.4	No [b]	d, x	$[1^-]$ [b]	3
$D_s^+(0^-)\ D_{s1}^-(2536)(1^+)$	4503.4	387.0	No	d, x	–	–
$D_s^+(0^-)\ D_{s2}^{*-}(2573)(2^+)$	4540.2	423.8	x	d	2^-	2
$D_s^{*+}(1^-)\ D_{s1}^-(2460)(1^+)$	4571.6	455.2	d, x	d, x	$0^-, 1^-, 2^-$	3
$D_{s0}^{*+}(2317)(0^+)\ D_{s0}^{*-}(2317)(0^+)$	4635.4	519.0	No	d	–	–
$D_s^{*+}(1^-)\ D_{s1}^-(2536)(1^+)$	4647.2	530.8	d, x	d, x	$0^-, 1^-, 2^-$	3
$D_s^{*+}(1^-)\ D_{s2}^{*-}(2573)(2^+)$	4684.0	567.6	d, x	d, x	$1^-, 2^-, 3^-$	3
$D_{s0}^{*+}(2317)(0^+)\ D_{s1}^-(2460)(1^+)$	4777.2	660.8	x	d	1^+	4

[a] $J^P = 1^+$ forbidden by C symmetry.
[b] Proximity of these two channels may lead to binding. See text.

deuteron which binds via exchange of pions and other light mesons [4–9]. The question then arises as to whether a related mechanism can play a role in binding heavy hadrons which contain no u, d quarks. In this note we identify potential channels in which η exchange is the longest-range force, and can thus form bound states with quark content such as $(c\bar{s})(\bar{c}s)$. We predict masses based on the proximity to thresholds of charmed-antistrange and anticharmed-strange pairs. Such a proximity is a widespread feature of S-wave structures [10]. We do not estimate detailed binding energies in this brief note, addressing only the utility of η exchange as a signal for molecule formation. We discuss briefly the role of other, shorter-range, exchanges such as η', $f_0(980)$, and ϕ.

There have been observations [11–15] or failures to observe [16–18] a $J/\psi\,\phi$ resonance at 4140 MeV, which does not correspond to any known $D_s^{*+}D_s^{*-}$ threshold. Both η and ϕ exchange were considered in a work identifying the 4140 MeV state as a $D_s^{*+}D_s^{*-}$ molecule [19], with predicted $J^P = 0^+$ and 2^+ masses highly dependent on an arbitrary cutoff parameter. Such a molecule was also considered in Ref. [20], where the binding was due to η, σ, and ϕ exchange. The large binding energy in these two works is somewhat suspicious in view of the short range of these potentials. A recent work explains the 4140 MeV state as a mixture of 10% $D^{*0}\bar{D}^{*0}$, 10% $D^{*+}D^{*-}$, and 80% $D_s^{*+}D_s^{*-}$ [21]. If the $J/\psi\,\phi$ resonance at 4140 MeV is confirmed, it is likely to be due to a mechanism beyond the η exchange discussed here. For example, in Ref. [22] the 4140 MeV state is dynamically generated in the channels $D_s^{*+}D_s^{*-}$ and $D^*\bar{D}^*$ which are coupled by K^* exchange.

The pseudoscalar η cannot couple to a pair of scalar or pseudoscalar mesons, so some $(c\bar{s})(\bar{c}s)$ channels will receive a contribution to their binding from η exchange, while others will not. Thus no molecule will be expected near $D_s^+D_s^-$ threshold. (Ref. [23] suggests $X(3915)$ could be such a state.) In Table 1 we summarize possible resonances involving two D_s mesons which can be produced in $B \to KX$ decays. We take $M(D_s) =$

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