# Open- and Hidden-Charm Tetra-Quark Mesons and Related – $\mathbf{D^+_{s0}(2317)}$, $\mathbf{D_0(2400)}$ and X(3872) –

Kunihiko Terasaki
*Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
*Institute for Theoretical Physics, Kanazawa University, Kanazawa 920-1192, Japan*

Tetra-quark mesons can be classified into the following four groups,

$$\{qq\bar{q}\bar{q}\} = [qq][\bar{q}\bar{q}] \oplus (qq)(\bar{q}\bar{q}) \oplus \{[qq](\bar{q}\bar{q})\} \oplus (qq)[\bar{q}\bar{q}], \;\; (q = u, d, s, c), \tag{1}$$

in accordance with the difference of symmetry property of their flavor wavefunctions, where parentheses and square brackets denote symmetry and anti-symmetry of flavor wavefunction, respectively, under exchange of flavors between them. The above classification is again classified into $\bar{\mathbf{3}}_\mathbf{c} \times \mathbf{3}_\mathbf{c}$ and $\mathbf{6}_\mathbf{c} \times \bar{\mathbf{6}}_\mathbf{c}$ of the color $SU_c(3)$. The force between two quarks is attractive when they are of $\bar{\mathbf{3}}_\mathbf{c}$, while the corresponding force is repulsive when they are of $\mathbf{6}_\mathbf{c}$. Therefore, we take the $\bar{\mathbf{3}}_\mathbf{c} \times \mathbf{3}_\mathbf{c}$ state as the lower lying one. In this case, narrow widths of heavy tetra-quark mesons can be understood by a small overlap of color and spin wavefunctions. However, the same mechanism does not work in light tetra-quark mesons because of the non-perturbative property of QCD at a low energy scale, so that they can be broad.

From the experimental constraint,

$$R(D^+_{s0}(2317))_{\rm exp} = \left.\frac{\Gamma(D^+_{s0}(2317) \to D^{*+}_s\gamma)}{\Gamma(D^+_{s0}(2317) \to D^+_s\pi^0)}\right|_{\rm exp} < 0.059, \tag{2}$$

it is seen that the interaction causing the decay in the denominator is much stronger than the electromagnetic interaction. Because such a strong interaction is the well-known isospin conserving strong interaction, $D^+_{s0}(2317)$ should be an iso-triplet state. Such a charm-strange state cannot be the conventional $\{c\bar{s}\}$ system but can be realized by a tetra-quark state, for example, $\hat{F}^+_I \sim [cn][\bar{s}\bar{n}]_{I=1}$, $(n = u, d)$. On the other hand, its iso-singlet partner $\hat{F}^+_0 \sim [cn][\bar{s}\bar{n}]_{I=0}$ decays dominantly into radiative channels because the kinematically allowed $D^+_s\pi^0$ is an iso-triplet state and isospin non-conserving interactions are much weaker than the electromagnetic interaction as is well-known.

$X(3872)$ decays into two different final states with opposite $G$-parities, (and $C$-parities when isospin is conserved),

$$\frac{Br(X(3872) \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X(3872) \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3. \tag{3}$$

This is puzzling because the strong interaction conserves $G$-parity (i.e., $C$-parity and isospin). However, the above puzzle could be solved, if $X(3872)$ consists of two (approximately) degenerate states with opposite $G$-parities. Such a situation can be realized by $\{[cn](\bar{c}\bar{n}) \pm (cn)[\bar{c}\bar{n}]\}_{I=0}$ included in the last two terms of Eq.(1).

Widths of the scalar mesons $D^*_0 \sim \{c\bar{n}\}$ and $D^{*+}_{s0} \sim \{c\bar{s}\}$ are also studied by comparing with that of $K^*_0(1430)$ which has been considered as the scalar $\{c\bar{s}\}$ meson. Their widths are estimated to be $\Gamma(D^*_0) \sim 50$ MeV and $\Gamma(D^*_{s0}) \sim 40$ MeV. The former $\Gamma(D^*_0)$ is much smaller than the width $\Gamma(D_0) \sim 200 - 300$ MeV of the broad enhancement just below the peak of $D^*_2$ in $D\pi$ mass distribution which was observed by the Belle collaboration. But it was not smooth.

Therefore, more studies including the following items by the Belle collaboration are awaited:

- Observation of neutral and doubly charged partners $\hat{F}^{++}_I$ and $\hat{F}^0_I$ of the above $\hat{F}^+_I = D^+_{s0}(2317)$ in $B$ decays. (Their production in $e^+$-$e^-$ annihilation would be suppressed as was discussed in hep-ph/0804.2295.)
- Confirmation of the observation of the charm-strange scalar meson $D^+_{s0}(2317)[D^{*+}_s\gamma]$ in the $D^{*+}_s\gamma$ channel which is (approximately) degenerate with $D^+_{s0}(2317)$. It implies the existence of iso-singlet partner $\hat{F}^+_0$ of $\hat{F}^+_I$.
- Search for the conventional $D^{*+}_{s0}$ in $DK$ channels of $B$ decays. Its width would be $\Gamma(D^{*+}_{s0}) \sim 40$ MeV.
- More precise re-analysis of the $D\pi$ mass distribution just below the $D^*_2$ peak and observation of its structure containing the conventional $D^*_0$ and the very narrow non-strange partner $\hat{D}$ of the above $\hat{F}^+_0$ and $\hat{F}^+_I$. In this way, various models providing artificially large rates $\gtrsim 10$ keV for isospin non-conserving decay could be killed.
- Search for the decay $X(3872) \to J/\psi\pi^0\pi^0$ to confirm the isospin conservation in $X(3872)$ physics.
- Search for the $\omega\gamma$ decay of hidden-charm scalar meson $\hat{\sigma}^c \sim [cn][\bar{c}\bar{n}]_{I=0}$. This is the dominant decay and its rate is $\Gamma(\hat{\sigma}^c \to \omega\gamma) \sim 100$ keV in our model, while a unitarized chiral model predicts that the corresponding meson $X(3700)$ decays dominantly into the $J/\psi\gamma$ state and $\Gamma(X(3700) \to J/\psi\gamma) \sim 20$ keV.