Structure of X(3872) with hadronic potentials coupled to quarks

The inter-quark potentials diverge at large distance because of the color confinement of quarks. The inter-hadron potentials, on the other hand, vanish at large distance, because the interaction range is limited by the inverse pion mass.

What then is the effect of the coupling to the inter-hadron potentials in the inter-quark potentials and vice versa?

We consider, in this talk, the channel coupling between the inter-quark and inter-hadron potentials. We then derive the effective potential of hadrons by eliminating the quark channel in the Feshbach method [1]. In the case of the Yukawa type transition potential, we obtain the effective potential of hadrons,

$$
V(\mathbf{r},\mathbf{r'},E) = \frac{g_0^2}{E-E_0}\frac{e^{-\mu r}}{r}\frac{e^{-\mu r'}}{r'}, \tag{1}
$$

where g_0 is the coupling constant of the channel transition between quarks and hadrons, E_0 is the energy of the bound state of the quark degrees of freedom.

We show that the effective potential has non-locality and depends on the energy E.

There are two methods of converting non-local potentials into local ones. A formal derivative expansion decomposes directly a non-local potential in terms of the derivatives of the local potential.

In the HAL QCD method, one derives the local potential from the wave function $\psi_k(r)$ at a momentum $k = \sqrt{2mE}$ which is obtained by the non-local potential.

In the case of potential (1), we obtain at leading order,

$$
\begin{aligned}
V_0^{\rm formal}(r,E) &= \frac{4\pi g_0^2}{\mu^2(E-E_0)}\frac{e^{-\mu r}}{r}, \\
V_0^{\rm HAL}(r,E) &= \frac{1}{2mr\psi_k(r)}\frac{d^2}{dr^2}\left[r\psi_k(r)\right].
\end{aligned}
$$

Finally, we take $c\bar{c}$ as the quark channel and $D\bar{D}^*$ as the hadron channel to apply this study to $X(3872)$.

We construct the effective local $D\bar{D}^*$ potentials which reproduce the observed mass of $X(3872)$.

By analyzing properties of these local potentials, we discuss the structure of $X(3872)$.

[1] H. Feshbach, Ann. Phys. **5**, 357 (1958); ibid., **19**, 287 (1962).

[2] S.Aoki and K.Yazaki, PTEP **2022**, no.3, 033B04 (2022)

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