The six-quark structure of long-lived $D$-mesons and $\psi/J$

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Abstract

The harmonic quarks are applied to the analysis of quark structures of long-lived $D$-mesons and $\psi/J$. In the harmonic quark model the quarks of long-lived mesons ($\pi^0$, $\pi^\pm$, $K^\pm$, $K^0$, $B^0$, $B^\pm$) are weakly relativistic objects with the excess energy of valent quarks less than 7 MeV. In contrast to this, the long-lived $D$-mesons in two-quark standard have the apparent excess energies of a few hundred MeV. It was established that all long-lived $D$-mesons and $\psi/J$ have the six-quark structures. There are two valent quarks and two additional neutral quark-antiquark $u$-pairs. The quark structures of $D^0$, $D^\pm$, $D_s^\pm$ and $\psi/J$ are given. The excess energies of six-quark $D$-mesons also does not exceed 7 MeV. A six-color quark composition and the absence of two-quark $D$-mesons in the context of QCD are discussed.

1 Introduction

The harmonic quarks have proved that they are the powerful and effective tool for investigation of energy structure of hadrons [1]–[5]. This tool works equally well with both masses of long-lived hadrons and resonances. The hypothesis, that there is a simple analytical association of quark masses, was not created out of thin air, but it is actually a conclusion of observable regularity of a long-lived mesons mass spectrum [1]. The harmonic quarks/oscillators allowed to decrypt the spectrum of meson masses with an open charm [4], and to interpret [5] the precise data of collaborations CLEO and BELLE for mass differences of the charmed mesons [6, 7]. Thus, it may be considered proven that these differences are strictly quantized by harmonic quarks rest masses.

In the present work, we shall investigate the energy states and quark structures of the long-lived charmed mesons. This problem becomes important when we try to interpret the structures of long-living charmed mesons using the harmonic quarks. As was mentioned earlier in [4], the mass of long-lived $D$-mesons ($D^0$, $D^\pm$ and $D_s^\pm$) have an excess mass more than total mass of two valent harmonic quarks. At the same time, the harmonic quark concept and especially the calculation of their masses [1] is set the fact that the quarks in long-lived mesons, such as $\pi^0$, $\pi^\pm$, $K^\pm$ and $b^\pm$, are weakly relativistic objects.
The excess energy of these mesons, i.e. energy above rest mass of two valent quarks, do not exceed 7 MeV \[1\] and can be easily defined\[1\].

Table 1. The quark structures of long-lived mesons and the rest masses of their quarks.

| Meson   | Quark structure of meson | Mass of meson | Mass of quarks or oscillator, MeV/c² | Excess energy, MeV |
|---------|--------------------------|---------------|-------------------------------------|-------------------|
| \(\pi^0\) | \((\psi/\bar{\psi})\) | 134.98        | 134.25                              | 0.73              |
| \(\pi^+\) | \(u\bar{d}\)             | 139.57        | 134.25                              | 5.32              |
| \(K^+\)   | \(u\bar{s}\)             | 493.66        | 491.33                              | 2.33              |
| \(D^0\)   | \(c\bar{u}\)             | 1864.5        | 1517.72                             | 346.78            |
| \(D^+\)   | \(c\bar{d}\)             | 1869.3        | 1517.72                             | 351.58            |
| \(D_{s}^+\)| \(c\bar{s}\)            | 1968.2        | 1798.17                             | 170.03            |
| \(\psi/J\) | \(c\bar{c}\)            | 3096.916      | 2824.56                             | 272.35            |

As against them in long-lived \(D\)-mesons (\(D^0\), \(D^\pm\) and \(D_{s}^\pm\)), an excess energy differs approximately per two order and achieves values \(\approx 350\) MeV (see tab.1). Such values of excess energies are characteristic for resonances, but not for ground meson states which decay because of a weak interaction. There are no visible reasons, which hinder a decrease of this “superfluous” energy and a pion emission in the result of strong interaction.

The fig.1 is shown a scheme, which explains this problem. It demonstrates excess energy for long-lived mesons (\(\pi^0\), \(\pi^\pm\), \(K^\pm\), \(D^0\), \(D^\pm\), \(D_{s}^\pm\), \(B^0\), \(B_s\), \(B_{s}^\pm\)) and the first vector mesons with hidden flavors (\(\omega\), \(\psi/J\), \(\Upsilon(1S)\)).

Here it is necessary to explain, that we understand as excess energy (EE). The excess energy for \(\pi^\pm\), \(K^\pm\), \(D^0\), \(D^\pm\), \(B^\pm\), \(B_s\), \(B_{s}^\pm\) is a difference between a mass of meson and the summary mass of the valent quarks. Therefore, for example, for \(\pi^\pm\) and \(D_{s}^\pm\) it is

\[
EE(\pi^\pm) = M_{\pi^\pm} - M_u - M_d \quad \text{and} \quad EE(D_{s}^\pm) = M_{D_{s}^\pm} - M_c - M_s.
\]

For the second states of hadronic doublets to these values are added a mass differences of proper doublets. The choice of this scheme for second states has certain reasons that discussed in \[2, 4\]. So, for example, the excess energy for \(\pi^0\) and \(D^\pm\) corresponds to the following equalities:

\[
EE(\pi^0) = EE(\pi^\pm) - (M_{\pi^\pm} - M_{\pi^0}) \quad \text{and} \quad EE(D^\pm) = EE(D^0) - (M_{D^\pm} - M_{D^0}).
\]

For the vector mesons, in which the standard model guesses a presence of quark-antiquark pair of corresponding flavor, the excess energies are equal:

\[\text{The masses of the harmonic quarks } d, u, s, c \text{ and } b \text{ are correspondingly next } [2, 3]: 28.811, 105.441, 385.89, 1412.28 \text{ and } 5168.7. \text{ The energy of completed } u\text{-oscillator } (\psi/\bar{\psi}) \text{ is equal } 134.25 \text{ MeV. The notation is as in } [2, 3, 4].\]

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Figure 1: The excess energy of long-lived and first vector mesons.

\[ \text{EE}(\omega) = M_\omega - 2M_s; \quad \text{EE}(\psi/J) = M_{\psi/J} - 2M_c; \quad \text{EE}(\Upsilon(1S)) = M_{\Upsilon(1S)} - 2M_b. \]

On the fig. we may see three groups of states for long-lived mesons. In the first group an excess energy is small and plus, i.e. quarks in this group of mesons are weak relativistic objects. In the second group a large negative excess energies are observed for the mesons with \( b \) quarks. The binding energy in these mesons is great and it defines by excess energy itself of \( b \)-quark, i.e. its donor properties [4]. In the given work, the object of investigation is third group, which has the mesons with \( c \) quarks and with great positive excess energies.

At sequential using of the harmonic quark model, we should suppose that the quarks in all long-lived mesons are weakly relativistic objects. From here follows, that the greatest part of excess energy in mesons \( D^0, D^\pm \) and \( D_s^\pm \) should be concentrated in masses of quarks and the complete oscillators, i.e. a quark structure of these mesons should be more complex, than in the standard quark model is guessed.

Let us note also that hereinafter we shall use only experimental masses of mesons [8].
The quark structures of long-lived charmed mesons

As it was noted earlier for pions [1,2], electromagnetic split of their masses is bound with the valent $d$-quark, as at approximately equal momentum of quarks in pions the lightest harmonic $d$-quark should have the greater kinetic energy, than a $u$-quark. This standing is valid and for various kaons, baryons and for $D$-mesons also. There are no the meson multiplets with the inverse order of mass split. From a position of the harmonic levels as a gang of harmonic oscillators, mesons $D^0$ and $D^±$ belong to one level [3], but their second valent quarks accordingly $u$ and $d$ have the rest masses distinguishing approximately in 3.6 times. Both mesons are in one potential well, but in view of the previously mentioned, the mass of a meson $D^±$ with the valent $d$-quark should be more masses of a meson $D^0$. Really, the difference of their masses is same as and at pions.

Now we shall estimate the excess energy of quarks in a meson $D^0$, using their values for the first long-lived mesons of other flavors ($\pi^0$, $K^±$ and $b^±$). These values accordingly the following: 0.725; 2.33 and 4.89 MeV. The choice of these mesons, instead of three other long-lived mesons ($\pi^±$, $K^0$ and $b^0$), is determined by that the second group has the valent $d$-quark and is more suitable for definition of excess energy in a meson $D^±$. We simply do not have other variants for $D^0$. Taking into account the electrical charges of mesons and heavy quarks in mesons ($D^0$ and $b^±$), we make a proportion:

$$EE(D^0)/EE(\pi^0) = EE(b^±)/EE(K^±)$$

(1)

The ratio (1) is balanced enough. Both in left-hand, and in the right ratios are a mesons with massive quarks through generation, i.e. quarks have same charges ($b$- and $s$-quarks for the right ratio). From here, we find $EE(D^0) = 1.52$ MeV. Then the sum of rest masses of quarks $D^0$ is approximately equal 1863.0 MeV. The energy above mass of the valent quarks ($c$ and $\bar{u}$) shall be equal approximately 345.3 MeV. This energy should be a rest mass of electrically neutral and colorless group of quarks. It can consist only from $u$- and $d$-quarks and their oscillators as the energy of $s$-oscillator more and is equal 491.33 MeV.

Really, the analysis has shown, that this energy is matched with equivalent mass of the most simple symmetric quark combination (minimum of quarks and oscillators):

$$u\bar{u} + \bar{u}\bar{u}$$

The energy of last group is equal 345.13 MeV. Next combination with such energy contains already eight quarks, including six $d$-quarks. This group should be rejected for many reasons. Here is one of them. At least four $d$-quark are bound with each other, i.e. they are the free, and each of them demands additional energy approximately same as the valent $d$-quark surveyed above. This energy is more on one order than our estimation.
of excess energy in \( D^0 \). The next rejected combination have already 12 \( d \)-quarks. That is all, there are not one more other neutral quark group. Thus, the first combination with the minimum number of quarks is single acceptable neutral group. From here we define, that excess energy of quarks in \( D^0 \) is equal 1.65 MeV and the mass of all quarks is equal 1862.85 MeV. At present, we may only carefully congratulate itself with this result. The quark composition of the \( D^0 \) is next:

\[
\begin{align*}
\bar{c}u + u\bar{u} + \bar{u}u
\end{align*}
\]  

(2)

In [2] we noted that completely neutral shells (colorless electrically neutral shells) from six quarks of one flavor correspond to a QCD and consequently should be inconvertible configurations, as well as integrating of quarks in completely neutral pairs. Really, we managed to show, that shells from six quarks are present at some resonances [2, 3]. However, inconvertible structure from six quarks in long-lived meson is the unexpected result which necessarily in the further to discuss and to check.

The replacement of \( n\bar{n} \)-oscillator in \( D^0 \) on quarks \( u\bar{d} \) with the same mass give to us at once the quark structure of \( D^+ \) with excess energy 6.45 MeV:

\[
\begin{align*}
\bar{c}d + u\bar{u} + u\bar{u}
\end{align*}
\]  

(3)

The EE in \( D^\pm \) is little more, than EE with the \( d \) valent quarks in \( \pi^\pm \) and \( K^0 \) (5.32 and 6.34 MeV accordingly). It is possibly bound simply with larger number of quarks in \( D^\pm \).

Now we shall estimate the excess energy in a meson \( D^\pm_s \). On the one hand a EE of \( D^\pm_s \) should be more, than for \( D^0 \) (1.65 MeV) because the valent quarks of the \( D^\pm_s \) are unipolar, but on the other hand it should be less, than for meson \( D^\pm \) (6.45 MeV) because \( s \)-quark on one order is heavier than \( d \)-quark. The \( K^\pm \) with EE 2.33 MeV can be by the analog for \( D^\pm_s \), however \( D^\pm_s \), probably, has more quarks. The reader, we shall take mean quantity on three values since it is all that we can. Therefore, mean value is equal \( 3.48^{+3}_{-1.8} \) MeV and the rest mass of quarks is equal about 1964.72 MeV. The limitations (+3 and -1.8) follow from EE(\( D^\pm \)) and EE(\( D^0 \)). The surplus of mass above the valent quarks is equal 166.6 MeV. Simple exhaustive search of variants has shown that energy 166.6 in boundaries \( \pm 3.0 \) MeV is not interpreted as neutral group from \( u \)- and \( d \)-quarks and their oscillators.

However, we have one more chance. In [4] it was noted, that in the strong central field of \( c \)-quark the mass rank \( s \)- and \( u \)-quarks can be changed down to their state in complete harmonic oscillators. For \( s \)-quark, this state is \( s^\circ \) with energy 245.666 MeV. The surplus of mass above the valent quarks in this case will be equal 306.8 MeV. This energy can be precisely represented also by four \( u \)-quarks:
\[ for \ D_s^+ \quad \bar{u} + \bar{u} + u + \bar{u} \quad for \ D_s^- \quad u + u + \bar{u} + \bar{u} \] (4)

The rest mass of these quarks is 306.82 MeV. Certainly, we was lucky with accuracy, but nevertheless the quark structure of a meson \( D_s^+ \) may be next:

\[ c\bar{s} + \bar{u} + \bar{u} + u + \bar{u} \] (5)

From (5) follows that excess energy of quarks in \( D_s^\pm \) is equal 3.44 MeV, and the rest mass of quarks is equal 1964.76 MeV.

Thus, we have received compositions with six harmonic quarks for all long-lived \( D \)-mesons of base levels. The rest mass of all quarks for these mesons are spotted with precision about 0.1 MeV (see tab.2). Therefore, the error of definition of EE will about 0.4 MeV, because the experimental mass error is equal 0.4 MeV \[ 8 \] and it gives the greatest contribution.

2.1 Application of harmonic quarks to \( \psi/J \)

In spectrum of charmonium, the \( \psi/J \) is first long-lived meson with hidden charm (\( \eta_c \) is a resonance with width about 25 MeV). Therefore, with above-said point of view, we may expect that its quarks are also the weak relativistic objects. The mass difference between \( \psi/J \) and rest mass of two \( c \)-quarks is equal 272.35 MeV and may consist only of \( u \)- and \( d \)-quarks. The excess energy of \( \psi/J \) may be estimated simply as mean value between the excess energies (now known to us) of \( D_s^0, D_s^\pm \) and \( D_s^{\pm} \), i.e. as 3.85 MeV (see tab.2). From here, the rest mass of neutral quark group is equal 268.50 MeV. We was again lucky with accuracy. This mass is simply energy of two \( u \)-oscillators (268.50 MeV). Therefore, the quark structure of \( \psi/J \) may be noted down as symmetric group out of six quarks:

\[ c\bar{c} + \bar{u} + u + \bar{u} + \bar{u} + u \] (6)

As it was mentioned above, a \( c \)-quark has acceptor properties and each heavy quark can capture one of \( u \)-oscillators. Then the configuration (6) may be represented as the molecule of two quark atoms:

\[ c + \bar{u} + \bar{u} \quad and \quad \bar{c} + u + u \] (7)

The EE of \( \psi/J \) is equal 3.85 \( \pm \) 0.15 MeV. Indicated error corresponds with precision which the quark masses is defined \[ 3 \]. Summarized results are given in table 2 and the new positions of excess energy for \( D \)-mesons are pointed out on fig.1 by crosses.
Table 2. The quark structure of long-lived mesons, the rest mass and excess energies of their quarks.

| Long-lived mesons | Quark structure of meson | Rest mass of quarks, MeV/c² | Excess energy, MeV |
|-------------------|--------------------------|-----------------------------|-------------------|
| π⁺                | ud                       | 134.25±0.007                | 5.32±0.007        |
| K⁺                | uś                       | 491.33±0.025                | 2.33±0.030        |
| D⁰                | cū + (ū(ū) + uū)         | 1862.85±0.09                | 1.65±0.41         |
| D⁺                | cd + uū + uc            | 1862.85±0.09                | 6.45±0.41         |
| D⁺                 | cū + (ū) + ū + (ū(ū))  | 1964.76±0.10                | 3.44±0.51         |
| ψ/J               | cc + (ū(ū) + (ū(ū))    | 3093.06±0.15                | 3.85±0.15         |
| b⁺                 | ub                       | 5274.11±0.26                | 4.89±0.56         |

The errors of excess energy in tab.2 are defined as squared errors between experimental mass errors of mesons [8] and the errors of rest mass.

3 Discussion

This and earlier done investigations of D-meson structures with the using of the harmonic quarks leads us to the conclusion about discovery of new unknown phenomenons in a microcosm. At first, we discovered that some D-transitions are precisely quantized by the masses of harmonic quarks [5]. Secondly in present work, we found the unusual quark structures of long-lived ground D-mesons and ψ/J.

What are the probability that these discoveries are true? This matter was investigated earlier in [3, 4]. So, the probability of an accidental coincidence of actual and model spectrums of hadrons up to 1000 MeV is estimated in [3] as value less than $10^{-6}$. For actual and model spectrums of mesons with open charm [4], the variance of correspondence is six times less in comparison with [3]. Here already the probability of an accidental coincidence is approximately equal $10^{-12}$. The independent value from two works is less than $10^{-18}$. After [5] and present article, it becomes progressively less.

3.1 Composition Six

We have detected the six-quark compositions in long-lived D-mesons and ψ/J. The author supposes that all they are the six-color quark compositions with full set of colors (red, green and blue) and anticolors. The compositions of $D^±$ and $ψ/J$ with two identical quark-antiquark pairs testifies in favour of this assumption. At ground state these pairs must have the same quantum numbers (L=0, S=0) except color only.
The scheme on fig.[2] illustrates two type of quark structure for $D^0$:
1. two-quark strong coupling with long tube;
2. six-quark strong interaction with short tubes.

Figure 2: The illustrative scheme of strong interaction in $D^0$ for two- and six-quark configurations.

The six-color composition can explains a too large excess energy in $D$-meson and removes the contradiction between two groups of long-living mesons (see fig.1). The contradiction is inevitable only for two quark modes in standard quark model. Two-quark long-living meson must often be in state with very extended color tube and maximum potential energy. There are many chance for condensation of EE in the form of quark-antiquark pairs on acceptor trap of $c$-quark. It is one of possible ways the six-quark composition might be formed.

At the same time, perhaps, the two-quark $D$-mesons not exist in the nature.

3.2 QCD and $D$-mesons

Is this result unexpected? In addition, how nevertheless all this is according with QCD?

The heavy $c$-quark introduces an asymmetry in $D$-mesons and automatically becomes the valent quark together with its anticolor partner. Any other quark-antiquark pair will consist from $u$-quarks (see tab.2) with probably another color and an anticolor, which differ from colors of $c$-quark and its partner. A presence in a meson of others completely
neutral quark-antiquark pairs remains hidden for standard quark model, as well as, for example, a sea quark-antiquark pairs. However, for $D$-mesons these pairs are functional, since they are necessary units of the complete color group, i.e. the composition 6. The shells with configuration 6 in the harmonic quark model were expected and detected earlier in [3]. These shells are guessed in structures $\rho(770), K^*, \varphi, a(1474)$ and $p\bar{p}$. This property is not unique for the charmed mesons. The distinctive feature of $D$-spectrum from light and strange mesons is the full absence of long-living $D$-mesons with one quark-antiquark pair.

Two-quark long-lived $D$-meson in the harmonic model should have the mass about 1520 MeV with excess energy in range 1-7 MeV similar mesons $\pi^\pm, K^\pm, B^\pm$. However the charmed mesons with such masses are not observed, we have $D$-mesons with masses about 1870 MeV and, as shown in this work, in six-quark configurations with the mentioned above excess energies (1.65 for $D^0$ and 6.45 MeV for $D^\pm$).

The next scenario is most probable.

The QCD and absence of two-quark $D$-mesons tell to us, that color interaction of a $c$-quark and its partner is insufficient for formation of long-lived two-quark meson. It means, an exchange of color gluons between $c$- and $u$-quarks is too small. A weak gluon activity can give a bad allocation and bad compensation of colors on space-time and a break of asymptotic freedom. Then, as the result, there will not of an enough strong coupling between quarks for formation of two-quark $D$-mesons. Other quarks have two-quark long-living mesons (except $t$-quark) and, hence, enough intensive gluon exchange for an establishing of antishielding and colorless superposition $R\bar{R} + G\bar{G} + B\bar{B}$, i.e. a formation of strong coupling.

Just properties of $c$-quark show up in a weakening of gluon exchange.

Though in QCD an emission rate of gluons decreases with gain of quark mass, but this phenomenon is not bound with mass. Fig.1 and existence of two-quark mesons with a $b$-quark are sufficient arguments about secondary role of quark mass in this respect. This property of $c$-quark, more probably, is bound somehow with its electrical charge, i.e. with structure of charges $(1/3e + 1/3e)$ and of magnetic field inside a quark. It is appropriate mention here that the $u$-quark demonstrates a splittable structure of electric charge $[4, 5]$. In six-color six-quark configuration the gluon exchange of $c$-quark is much more because of additional interaction with other light quarks. At addition to this exchange there will an intensive background of gluon exchange between five light quarks. Thus, it is possible that with the help of additional quark pairs the next properties will be reached:

1. An intensive gluon exchange;
2. The necessary degree of an antishielding around a color charge of $c$-quark;
3. An asymptotic freedom of the movable $u$-quarks;

The result is the six-quark $D$-mesons with masses 1864.5, 1869.3 and 1968.2 MeV.
The reader, we might summarize aforesaid in other words, the shielding by the real quark-antiquark pair is the necessary condition for comfortable life of $c$-quarks in mesons (hadrons?).

Similar reasonings can be valid and for other mesons which contain $c$-quark(s), and also, perhaps, for their excited states (resonances). Still we not known the reason why $c$-quark should consist in six-color quark group. Perhaps, it is bound with features of its exchange of color gluons and/or its acceptor ability. Anyhow, it is bound with especial properties of $c$-quark only.

4 Conclusion

Thus, the harmonic quarks perfectly work with first ground mesons of all flavors. It gives us the quark structures and exact additional energies of the next ground mesons: $\pi^0$, $\pi^\pm$, $K^\pm$, $K^0$, $D^0$, $D^\pm$, $D_s^\pm$, $\psi/J$, $B^0$ and $B^\pm$. All quarks of these mesons are a weak relativistic objects as it have to be for ground states. Only three mesons with $b$-quarks ($B_s$, $B_c^\pm$ and $\Upsilon(1S)$) wait their turn. However, this investigation shall more difficult because a $b$-quark is a donor (see fig.1) and while we not know the quantity of energy which $b$-quark may give away.

The QCD lattice simulation can be very efficient for an examination of new phenomenons and a development of harmonic quark model.

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