Comment on the narrow charmonium state of Belle at 3871.8 MeV as a deuson

Nils A. Törnqvist
Department of Physical Sciences, University of Helsinki, POB 64, FIN–00014

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Abstract

It is pointed out that the narrow charmonium state at 3871.8 MeV reported by the Belle collaboration is very likely a $D\bar{D}^*$ deuteronlike meson-meson state called a deuson. It was predicted near the $D\bar{D}^*$ threshold over 10 years ago. Its spin-parity would be $0^{-+}$ or $1^{++}$ and an important decay mode should be via $D^0\bar{D}^{*0}$ to $D^0\bar{D}^{*0}\pi^0$. Its width to that channel should then be of the order 50 keV.

Note: A more detailed update of this unpublished note is in hep-ph/0402237.

No doubt the deuteron is a multiquark state which to a good approximation can be understood as a proton-neutron system bound by mainly pion exchange. Many years ago I asked the question: for which quantum number $s$ is the well known pion exchange mechanism attractive and comparatively large? This was found to be the case for several light meson-meson channels with quantum numbers where problematic resonances have been seen. Then I predicted for heavy mesons using a similar framework as for the deuteron many deuteron-like states, which are listed in table 1. See also Refs.

Very recently the Belle collaboration reported a new narrow charmonium state at 3871.8 ± 0.7 MeV and with a width smaller than their resolution (or $\Gamma < 3.4$ MeV). This is 60–100 MeV above the expected spin 2 $c\bar{c}$ ($^3D_{2s}$) state. The B-factory produces abundantly $B^{\pm}$ mesons through $e^+e^- \rightarrow \Upsilon(4) \rightarrow B^{+}B^{-}$ and they see the new state in the $\pi^+\pi^-J/\psi$ invariant mass distribution of $B^{\pm}$ decay to $K^{\pm}\pi^+\pi^-J/\psi$. They find $34.4 \pm 6.5$ events and a $8.6\sigma$ signal significance for the observed resonance peak.

This looks very much like one of the two first deuteronlike $D\bar{D}^*$ states at 3870 MeV predicted in table 1 (from table 8 of Ref.). (The states are of course all eigenstates of C-parity, or $|D\bar{D}^*| \equiv |\pm\bar{D}D^*|/\sqrt{2}$ although we above denote them $D\bar{D}^*$.) We note in particular:

\[\text{Note: A more detailed update of this unpublished note is in hep-ph/0402237.}\]
Table 1: Predicted masses\textsuperscript{2} of heavy deuteronlike states called deusons. These are close to the $DD^*$ and the $D^*D^*$ thresholds, and about 50 MeV below the $BB^*$ and $B^*B^*$ thresholds. All states have $I=0$. The mass values were obtained from (a rather conservative) one-pion exchange contribution only.

| Composite $J^{PC}$ | Mass [MeV] | Composite $J^{PC}$ | Mass [MeV] |
|---------------------|------------|---------------------|------------|
| $DD^*$              | 0$^+$      | $BB^*$              | 0$^+$      |
|                     | $\approx 3870$ |                       | $\approx 10545$ |
| $DD^*$              | 1$^{++}$   | $BB^*$              | 1$^{++}$   |
|                     | $\approx 3870$ |                       | $\approx 10562$ |
| $D^*D^*$            | 0$^{++}$   | $B^*B^*$            | 0$^{++}$   |
|                     | $\approx 4015$ |                       | $\approx 10582$ |
| $D^*D^*$            | 0$^{--}$   | $B^*B^*$            | 0$^{--}$   |
|                     | $\approx 4015$ |                       | $\approx 10590$ |
| $D^*D^*$            | 1$^{+-}$   | $B^*B^*$            | 1$^{+-}$   |
|                     | $\approx 4015$ |                       | $\approx 10608$ |
| $D^*D^*$            | 2$^{++}$   | $B^*B^*$            | 2$^{++}$   |
|                     | $\approx 4015$ |                       | $\approx 10602$ |

- Its spin-parity should be either 0$^{--}$ or 1$^{++}$. For other quantum numbers pion exchange is repulsive or so weak that bound states should not be expected.

- No $DD$ nor $BB$ deusons are expected since the three pseudoscalar coupling (in this case the $DD\pi$ coupling) vanishes because of parity.

- If isospin were exact the Belle state as a deuson would be a pure isosinglet with a mass very close to the $DD^*$ threshold. For isovector states pion exchange is generally one third weaker than for isoscalar states. Therefore all predicted states were isosinglets. (But see the comment on isospin breaking below).

- As a deuteronlike state with small binding energy (for the deuteron it is 2.22 MeV) the Belle state should be large in spatial size. It should then have a very narrow width since annihilation of the loosely bound $DD^*$ state to other hadrons is expected to be small, although states containing the $J/\psi$ are favoured compared to states with only light hadrons due to the OZI rule.

- A large part of its width should be given by the instability of its components or the $D^*$ widths, corrected for phase space effects. An important decay should be via $D^0\bar{D}^{*0}$ to $D^0\bar{D}^{*0}\pi^0$ since the other charge modes lie about 2 MeV above the resonance. One can, using isospin and $D^*$ width measurements\textsuperscript{9}, roughly estimate that that width should be of the order 50 keV.

- The observed peak (at 3871.8$\pm$0.7 MeV) is almost exactly at the $D^0\bar{D}^{*0}$ threshold (3871.2 MeV), while the $D^+\bar{D}^{*-}$ channel, 8.1 MeV higher, is closed by phase space.

*Isospin breaking* Since the binding energy of a $DD^*$ deuteronlike state is of the same order as the isospin mass splittings one should expect substantial isospin breaking. For a pure $I = 0$ state one has equal contribution of the
two components in $(|D^0\bar{D}^{*0}> + |D^+D^{*-}>)/\sqrt{2}$, but since $D^0\bar{D}^{*0}$ is 8.1 MeV lighter than $D^+D^{*-}$ it should have a greater weight than $D^+D^{*-}$. This means there is an $I = 1$ component in the state. It is interesting to note that then the decay of the deuson to $\rho J/\psi \rightarrow \pi^+\pi^- J/\psi$ would not be completely forbidden. There are indications of this in the experiment [6]. On the other hand the decay chain $\sigma J/\psi \rightarrow \pi^+\pi^- J/\psi$, where $\sigma$ is any isoscalar object, is forbidden by spin-parity for a $J^{PC} = 0^-$ or $1^{++}$ deuson. Thus one should expect some $\rho J/\psi \rightarrow \pi^+\pi^- J/\psi$, although suppressed by isospin.

The heavier the constituents the stronger is the binding, since the kinetic repulsion becomes smaller and is more easily overcome by the attraction from the potential term. Thus as seen from table 1 the $DD^*$ and $D^*\bar{D}$ systems are barely bound but for $BB^*$ and $B^*\bar{B}$ the binding energy is $\approx 50$ MeV. (The pion is always too light to be itself a constituent.)

An uncertainty in the calculation [2] was the $D^*$ coupling to $D\pi$, which was modelled from the $NN\pi$ coupling. We predicted a $D^{**} \rightarrow D^0\pi^+$ width of 63.3 keV in excellent agreement with the recent measurement of $65 \pm 3$ keV [9]. This increases the reliability of that calculation.

We conclude with a few general comments. For flavour exotic two-meson systems ($I = 2$, double strange, charm or bottom), such as $DD^*$ or $B^*B^*$, pion exchange is always either weakly attractive or repulsive. Calculations do not support such bound states to exist from pion exchange alone, and shorter range forces are expected to be repulsive. Should $BB^*$ states exist, however (See [4]), they would be quite narrow since they would be stable against strong decays.

Another recently seen state where pion exchange should be important is the BES state [10] seen in $J/\psi \rightarrow \gamma p\bar{p}$ near the $p\bar{p}$ threshold. Pion exchange should be attractive for a pseudoscalar $1S_0$ state, although a 17 MeV binding energy for a state with mass 1859 MeV seems a little difficult to obtain with pion exchange alone.

As to the recent narrow charm-strange resonances seen by the BaBar and CLEO collaborations at 2317 MeV [11] and 2460 MeV [12] 30-40 MeV below the $DK$ respectively $D^*K$ threshold pion exchange is not expected to play a dominant role. These states (if $J^{PC} = 0^{++}$, respectively $1^{++}$) should be distorted from naive expectations by the strong S-wave cusp at the above mentioned thresholds. See [13, 14]

A more detailed understanding with further experimental information on the Belle charmonium state is important. If the above comments are supported by data it would open up a completely new spectroscopy. It would also throw new light on many problematic light resonances in particular the $\eta(1410)$ and $\eta(1480)$ resonances just above the $K\bar{K}^*$ threshold.

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