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FLAVOUR INDEPENDENCE OF FORCES BETWEEN QUARKS

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A B S T R A C T

Experimental evidence from the J/ψ and γ spectra on the one hand and from the observation of mesons with visible charm and visible "beauty" lead to a non-trivial test of flavour independence of forces between quarks.

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A typical property of QCD¹⁾ is that the coupling between quarks and gluons is independent of the flavour of the quarks. This is because this coupling has to be equal to the gluon's self-coupling, typical of the non-Abelian character of the theory²⁾. It is of course desirable to accumulate as much direct and indirect experimental evidence of this fact. So far, for the particles not containing b quarks one can say that there are good indications in favour of flavour independence, for instance in the study of the hyperfine splittings of mesons and baryons³⁾.

In the sector involving b quarks, one has already indications of flavour independence of the forces between quarks from the comparison of the J/ψ spectra and γ spectra. It has been pointed out by several authors^{4),5)} that it is possible to fit both spectra by a common potential in the Schrödinger equation, especially if one takes into account asymptotic freedom effects in the short range part of the potential. One parameter which is rather accurately determined by the fit is the quark mass difference, which Quigg and Rosner⁶⁾, using the inverse scattering, find to be:

$$M_b - M_c = 3.455 \text{ GeV} \quad (1)$$

The absolute magnitude of the masses of each quark is not as well determined. A change of the quark mass can be partly compensated by adding a constant or very slowly varying term to the potential.

In fact a general lower bound was obtained by Grosse and the author⁷⁾ from the masses of the J/ψ , ψ' , and γ :

$$M_b - M_c > 3.29 \text{ GeV} \quad (2)$$

assuming that the flavor independent potential $V(r)$ satisfies the conditions

$$\left(\frac{d}{dr}\right)^3 r^2 V \geq 0 \quad \lim_{r \rightarrow 0} \left(2rV + r^2 \frac{dV}{dr}\right) > -\infty \quad (3)$$

$$\frac{d}{dr} \frac{1}{r} \frac{d}{dr} \left[2V + r \frac{dV}{dr}\right] < 0.$$

These conditions are fulfilled for instance by any superposition of attractive power potentials r^α with $\alpha \geq -1$ (Coulomb) and $\alpha \geq 2$ (harmonic oscillator).

The above determination does not take into account spin effects. Since the mass of a $1^{--} Q\bar{Q}$ system is $1/4$ times the hyperfine splitting above the centre of gravity of the singlet and triplet levels, the mass of the c quark will be lowered by $1/8(M_{J/\psi} - M_{\eta_c}) = 13$ MeV, according to the recent observation of the crystal ball group at SLAC⁸⁾. For the mass of the b quark the shift will be about $13 \times M_c/M_b = 4$ MeV, in the approximation where the potential is linear, where $|\Psi(0)|^2/M$ is constant. These effects are very small and would lead to replace (1) by:

$$M_b - M_c = 3.465 \text{ GeV} \quad (4)$$

What precedes constitutes to a certain extent a test of the equality of the $b\bar{b}$ and $c\bar{c}$ forces. What we want to point out is that one can also exploit the information coming from mesons with visible charm ($c\bar{d}$, $c\bar{u}$) visible beauty ($b\bar{d}$, $b\bar{u}$) and more generally systems made of a heavy quark Q and a light antiquark $\bar{q}$ (as we shall see the F meson is not very appropriate in this respect). It has been noticed⁶⁾ that if we define the mass of a $Q\bar{q}$ system as $M_Q + \Delta(Q)$, $\Delta(Q)$ becomes practically independent of M_Q for large M_Q , because the system behaves like a system with a fixed centre. This is legitimate if the energy (including mass) of the light quark is small compared to M_Q (I am grateful to F.E. Low for pointing out to me that energy, rather than rest mass, is the relevant quantity). For the D mesons such a condition is reasonably satisfied as discussed in Ref. 6): Quigg and Rosner propose, for the pseudoscalar states:

$$\Delta(b) - \Delta(c) \simeq 33 \text{ MeV} \times \left(1 - \frac{M_c}{M_b}\right) \simeq 20 \text{ MeV}. \quad (5)$$

It happens that preliminary announcement has been made at the E.P.S. 1979 Geneva Conference⁹⁾ of the observation of a possible candidate for a meson with visible beauty of mass 5.3 GeV decaying into $J/\psi + K + \pi$, which according to Fritzsche¹⁰⁾ is expected to occur with a 3% branching ratio. This finding still has to be confirmed, and new data are being collected and analyzed at the

time of writing of this paper, but it is not forbidden to speculate as if this was firmly established. From the previous discussion we see that the mass difference between the pseudoscalar mesons with visible beauty and visible charm should be equal to the mass difference of the corresponding quarks with a possible correction of 20 MeV. Hence we get

$$M_b - M_c = 5.3 - 1.87 - 0.02 = 3.41 \text{ GeV. (6)}$$

It is difficult not to be impressed by the remarkable agreement between (4) and (6). Eq. (4) was obtained assuming equality of the $(b\bar{b})$ and $(c\bar{c})$ forces, while Eq. (6) came from the equality of the $(b\{\frac{\bar{u}}{d}\})$ and $(c\{\frac{\bar{u}}{d}\})$ forces. This constitutes therefore a test of the flavour independence of the forces.

One could ask oneself whether the test is really meaningful. What happens if one disregards binding energies and uses a purely additive model in terms of quark masses? Then the estimate (4) reduces to $M_b - M_c = \frac{1}{2} (M_Y - M_{J\psi}) = 3.18 \text{ GeV}$ while the estimate (6) is replaced by 3.43 GeV. These numbers are significantly different from one another because one can generously estimate the theoretical uncertainty to be less than 50 MeV.

Turning the argument around, and taking the pessimistic view that the previously reported observation might not be confirmed, we could say that it would be extremely worrying not to observe a meson with visible beauty in the interval 5.27 to 5.37 GeV.

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ADDENDUM

After completion and typing of this work my attention was drawn by M.K. Gaillard on the report by Quigg, Rosner and Thacker, Fermilab pub. 79/52, which contains in particular the prediction of 5.31 GeV for the mass of visible beauty.

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