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PREDICTIONS ABOUT THE DECAYS OF THE B-MESONS*

by

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ABSTRACT

Extrapolating to the b sector a model applied to charm decay, the differences expected between B_s^0, B_d^0 and B_u^- lifetimes are discussed. No significative differences ($\leq 5 \sim 10\%$) are predicted.

Key-words: Non spectator; Lifetime of B mesons; Gaussian wave function.

A simple model of charm decay has been formulated recently[(1)] and applied with success to various process[(2)].

We certainly can not review the model here (the reader is referred to Ref. 1); for our present purposes, suffices to recall our starting assumption that the quarks produced in a decay behave as free particles only up to a separation distance xo of the order of ~ 0.3 Fm (i.e. $\sim 1.5\,\mathrm{GeV}^{-1}$), Above this separation, the probability that these quarks are still present is assumed to decrease as a gaussian.

Among many other consequences, the model predicts that the so-called "non-spectator decay diagrams" are sizeable and not at all negligeable as was originally believed[(3)].

In this paper, we explore what predictions we would obtain when generalizing the model of Ref. 1 to the b sector. Contrary to previous authors[(4)] we conclude that no significative differences between the lifetimes of the different B mesons are to be expected. Basically two new complications arise when comparing with the case of charm decay. The first is that we can not neglect any more the mass when the production involves charmed quarks. This simple fact has many interesting facets[(5)] which we shall not discuss here. From our point of view, it will simply mean that we will not be able to perform all integrations analytically but we will have to resort to a numerical integration. The second point is that we do not know, a priori, that the same value of xo (the distance above which hadronization becomes important) should be used for b as for c decay. We shall, bypass the difficulty by plotting the results as a function of our (only) parameter x_0. Ultimately, the extrapolation of the ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to u^+u^-)$ will support the conjecture that xo may, at most, have a very mild energy variation. This problem will be considered in detail in a forthcoming publication$^{(6)}$.

The various diagrams that give contribute to the decays of the various B mesons, B_u^-, B_d^0 and B_s^0 are shown in Figs. 1,2,3.

For each decay, we have the same spectator diagram (occasionally also denoted by W.R. for "W-Radiation"). The second class of diagrams ("non spectator" diagrams) are of the kind "W.A." i.e. W-Annihilation for the B_u^- decay and "W.E." i.e. W-Exchange for both B_d^0 and B_s^0. The non spectator B_u^- diagram will be neglected in what follows for being very small compared with the non spectator B_d^0 and B_s^0 diagrams; the former, in fact, is proportional to V_{ub} (in the Cabibbo-Kobayashi-Maskawa matrix) which is about ten times smaller than$^{(7)}$ V_{cb} to which the latter are proportional.

An immediate (and somewhat obvious) prediction is therefore that B_d^0 and B_s^0 should have a shorter lifetime than B_u^-. We shall, in what follow, try to quantify how much smaller these lifetimes ought to be.

As implicit in the above discussion, we do not consider here the case of B_c whose mass should lie considerably higher and whose experimental detection is, probably, much harder if at all possible.

Following now exactly the same procedure used in Ref. 1 without neglecting the masses of the quarks produced in the decay, for the non-spectator decay contributions of Fig. 2b and 3b we get the widths (up to color and mixing factors)

$$
\begin{aligned}
\Gamma = {} & \frac{G_F^2}{(2\pi)^{3/2}} f_B^2 x_0^3 M_B \int d\omega_c \frac{q_c}{\omega_c} \cdot \\
& \left\{ \exp - \left[\frac{x_0^2}{2} \left(\{ (M_B-\omega_c)^2 - m_1^2 \}^{1/2} + q_c \right)^2 \right] \cdot \right. \\
& \cdot \left\{ - \frac{(M_B-\omega_c)}{x_0^2} \omega_c - \frac{m_1 m_c}{x_0^2} - q_c \left[(M_B-\omega_c)^2 - m_1^2 \right]^{1/2} / x_0^2 - 1/x_0^4 \right\} + \\
& + \exp - \left[\frac{x_0^2}{2} \left(\{ (M_B-\omega_c)^2 - m_1^2 \}^{1/2} - q_c \right)^2 \right] \cdot \\
& \cdot \left\{ (M_B-\omega_c)\omega_c / x_0^2 + m_1 m_c / x_0^2 - q_c \left[(M_B-\omega_c)^2 - m_1^2 \right]^{1/2} / x_0^2 + 1/x_0^4 \right\}
\end{aligned}
\tag{1}
$$

where m_1 denotes the mass of the quark produced together with the charmed one in b decay (i.e. m_u for Fig. 2b and m_c for Fig. 3b); f_B is the B-decay constant which we will suppose to be the same for all B mesons and, for simplicity, to be the same as that for charm decay i.e. $f_B \simeq 200$ MeV; M_B is the B meson mass; x_0 is the hadronization length introduced in Ref. 1 which was estimated around 0.3 Fm (i.e. around 1.5 GeV^{-1}) in the case of charm decay.

The non spectator decay width (Eq. (1)) is shown in Fig. 4 as function of x_0; the continuous curve refers to the case $m_1 = m_c = 0$, the dashed curve to $m_1 = 0$, $m_c = 1.5$ GeV (B_d decay) and the dotted one to the case $m_1 = m_c = 1.5$ GeV (B_s decay).

Several comments are in order. First of all, the various curves differ very little up to $x_0 \sim 0.5$ GeV^{-1}. Their contribution becomes also rapidly insignificant as x_0 decreases to zero. Assuming x_0 in the present case to be comparable (perhaps a little lower) to the one appropriate for charm decay, the W.E. contribution to B_s decay (Fig. 3b) is about 100% larger than that of B_d decay (Fig. 2b) (under the assumption that decay and color constants are the same which may not be case$^{(8)}$) and both are larger than the Bμ W.A. contribution which we have argued to be negligible. Thus, if we identify the Bμ width with the spectator (W.R.) contribution (which is the same for all B's), we first of all have

$$\Gamma_{tot}(B_d) = \Gamma^{W.R.}(B_d) + \Gamma^{W.E.}(B_d) \tag{2}$$

or, parametrizing

$$\Gamma^{W.E.}(B_d) = k\Gamma^{W.R.}(B_u) \equiv k\Gamma_{tot}(B_u)$$

we find

$$\tau(B_u) \gtrsim (1+k)\tau(B_d) \tag{3}$$

and, from Fig. 4, we also have

$$\tau(B_u) \gtrsim (1+2k)\tau(B_s) \tag{4}$$

It should be stressed also that the above conclusions depend rather little on the exact value we take for m_c.

Let us now try to estimate the effect of the non spectator contribution i.e. of κ in eqs. (3,4).

The experimental measurements, aside from not distinguishing between B_u and B_d, have rather large uncertainties since they give$^{(9)}$

$$\begin{aligned} &\tau(B) = 0.85 \pm 0.17 \pm 0.21 \quad 10^{-12}\text{sec} \Longrightarrow \Gamma_{tot} \simeq 1.18 \quad 10^{12}\text{sec}^{-1} \\ &\text{(MARK II)} \\ &\tau(B) = 1.8^{+0.5}_{-0.4} \pm 0.4 \quad 10^{-12}\text{sec} \Longrightarrow \Gamma_{tot} \simeq 5.6 \quad 10^{12}\text{sec}^{-1} \\ &\text{(JADE)} \end{aligned} \tag{5}$$

In order to proceed, we take the value

$$\tau(B) \simeq 1.2 \quad 10^{-12}\text{sec} \Longrightarrow \Gamma_{tot} \simeq 8.3 \quad 10^{12}\text{sec}^{-1} \tag{6}$$

and we take the maximum value for Γ(W.E.) (Fig. 4) using also $f_B \simeq$ 200 MeV (as for charmed mesons$^{(1)}$). This gives, of course, an overestimate of the effect since other suggestions$^{(8)}$ lead to smaller f_B values.

In order the estimate the differences in the lifetimes of the various B mesons, we have now to choose the value of x_o at which to work. Different estimates are obtained for different values of x_o and we have no a priori way to choose between them. Fig. 4 shows that values such as $x_o \sim 0.5$ GeV^{-1} would enhance the differences in lifetimes whereas they would be reduced using the values $x_o \sim 1.5$ GeV^{-1} suggested by the analysis on c-decay$^{(1,2)}$.

Using $x_o \simeq 1$ GeV^{-1} (as it will turn out to be reasonable to do, see ref. 6), we find

$$\Gamma^{W.E.} = 0.65 \quad 10^{13} |V_{cb} V_{ud}|^2 F_c \ \sec^{-1} \tag{7}$$

In (7) we use(7) $|V_{cb}| = 0.05$ which is a rather poorly determined value to find

$$\Gamma^{W.E.} \simeq 1.53 \quad 10^{10} \ F_c \ \sec^{-1} \tag{8}$$

If for the color factor F_c we use the same approximate value used in the case of charm i.e.

$$[(2c_+ - c_-)/3]^2 \, [(c_+ + c_-)/2]^2 \simeq 2.3$$

corresponding to $c_+ \simeq 0.66$ and $c_- \simeq 2.3$ (in the case of B, this is probably overestimated since the renormalization point is higher), we find the approximate estimate

$$\Gamma^{W.E.} \simeq 3.50 \quad 10^{10} \ \sec^{-1} \tag{9}$$

Owing to eqs. 3 and 4, the above result allows to make the following predictions:

i) The W.E. contribution to B_d decay should not exceed some 5%, i.e. the B_u lifetime should be about 5% longer than the B_d lifetime;

ii) Similarly, the B_u lifetime should be ∿ 10 to 20% longer than the B_s lifetime.

The above are rather unique predictions as compared with other models with W.E. contributions(4) and, obviously, are subject to all the experimental uncertainties which we have mentioned already (on the values of $|V_{cb}|$, of f_B, of $\tau(B_u)$, of F_c etc.) and to the various theoretical ambiguities (on x_o, on F_c etc.).

It should also be stressed that the above values are already an overestimate: using a smaller value for f_B as suggested by various authors(8), would decrease the effect. This effect, on the other hand, would be enhanced by a smaller x_o. An x_o value of $\sim$ 0.5 GeV^{-1} would lead to a B_μ lifetime some 10% longer than B_d (and a B_d lifetime some 5-10% longer than B_s).

If, however, once computes in our model the value of

$$R = \frac{\sigma(e^+e^- \to \text{HADRONS})}{\sigma(e^+e^- \to \mu^+\mu^-)} \tag{10}$$

as it was done in Ref. 2a and one extrapolation it to higher energies, one finds that the best agreement is obtained for a value of x_o which is closer to 1 than to 0.5 GeV^{-1}. That x_o decreases from $\sim$ 1.5 to 1 GeV^{-1} going from the charm to the beauty mass is a feature which we are going to discuss in a separate publication(6).

Several applications of the previous ideas are of interest like, principally, the comparison of various exclusive channels since, for instance, $B_s \to D^+D^-$ only can occur via W.E. like $B_d \to D^+K^-$ (whereas $B_d \to D^-D^+$ only occurs via W.R.). These points will be discussed elsewhere.

What the present analysis teaches us, however, is the need to keep the effect of the charmed quark mass to get reliable estimates. One may worry that a similar conclusion could hold in the case of Ref. 1 with respect to keeping the effect of the strange quark mass into consideration. We have checked explicitly that the effect of retaining a strange quark mass different from zero (and up to ∿ 0.5 GeV) has a rather insignificant effect on the result of Ref. 1 (its effect, for $x_o \sim 1.5\ \mathrm{GeV}^{-1}$ is less than 4%).

In conclusion, we predict that the lifetimes of the various B mesons should not differ by more than 5-10% (as a consequence, the semileptonic branching ratios should also be nearly the same). These conclusions are much more conservation than other estimates (4).

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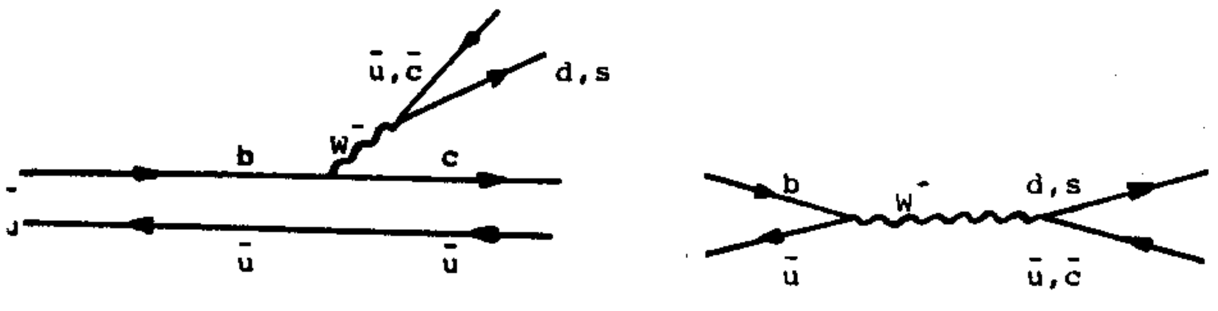
FIGURE CAPTIONS

Fig. 1 - (a) Spectator and (b) non spectator B_u^- decay diagrams.

Fig. 2 - Same as Fig. 1 for B_d^0 decay.

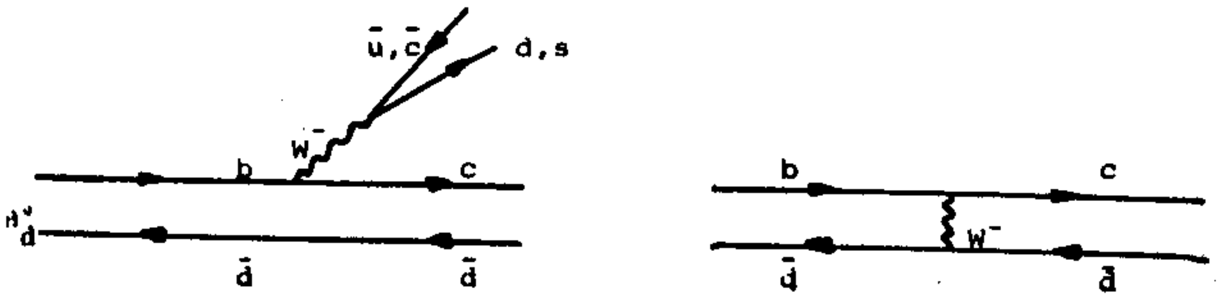
Fig. 3 - Same as Fig. 1 for B_s^0 decay.

Fig. 4 - x_o dependence of the rate for W-exchange diagrams. The continuous line corresponds to assuming zero charmed quark mass m_c. The dashed line corresponds to B_d^0 decay (i.e. $b\bar{d} \to c\bar{u}$) for $m_c = 1.5$ GeV. The dotted line corresponds to B_s^0 decay ($b\bar{s} \to c\bar{c}$) for $m_c = 1.5$ GeV.



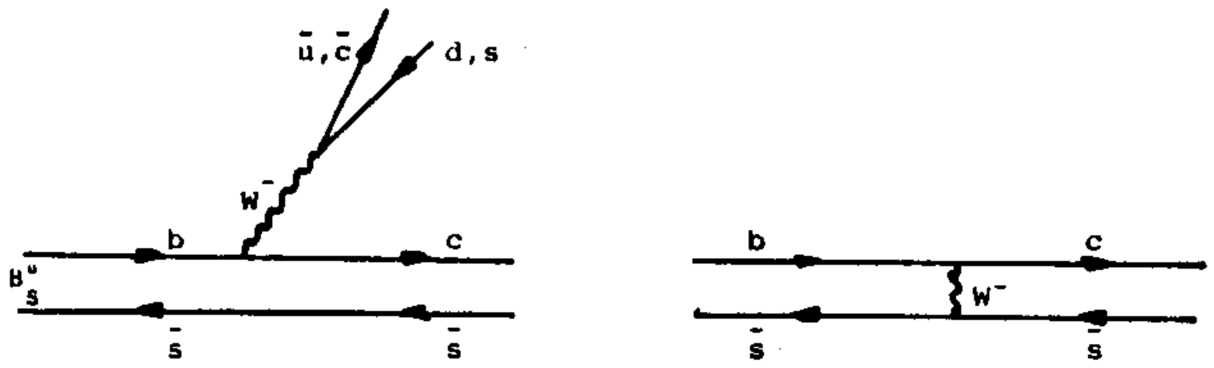
(a) (b)

Fig.1



(a) (b)

Fig.2



(a) (b)

Fig.3

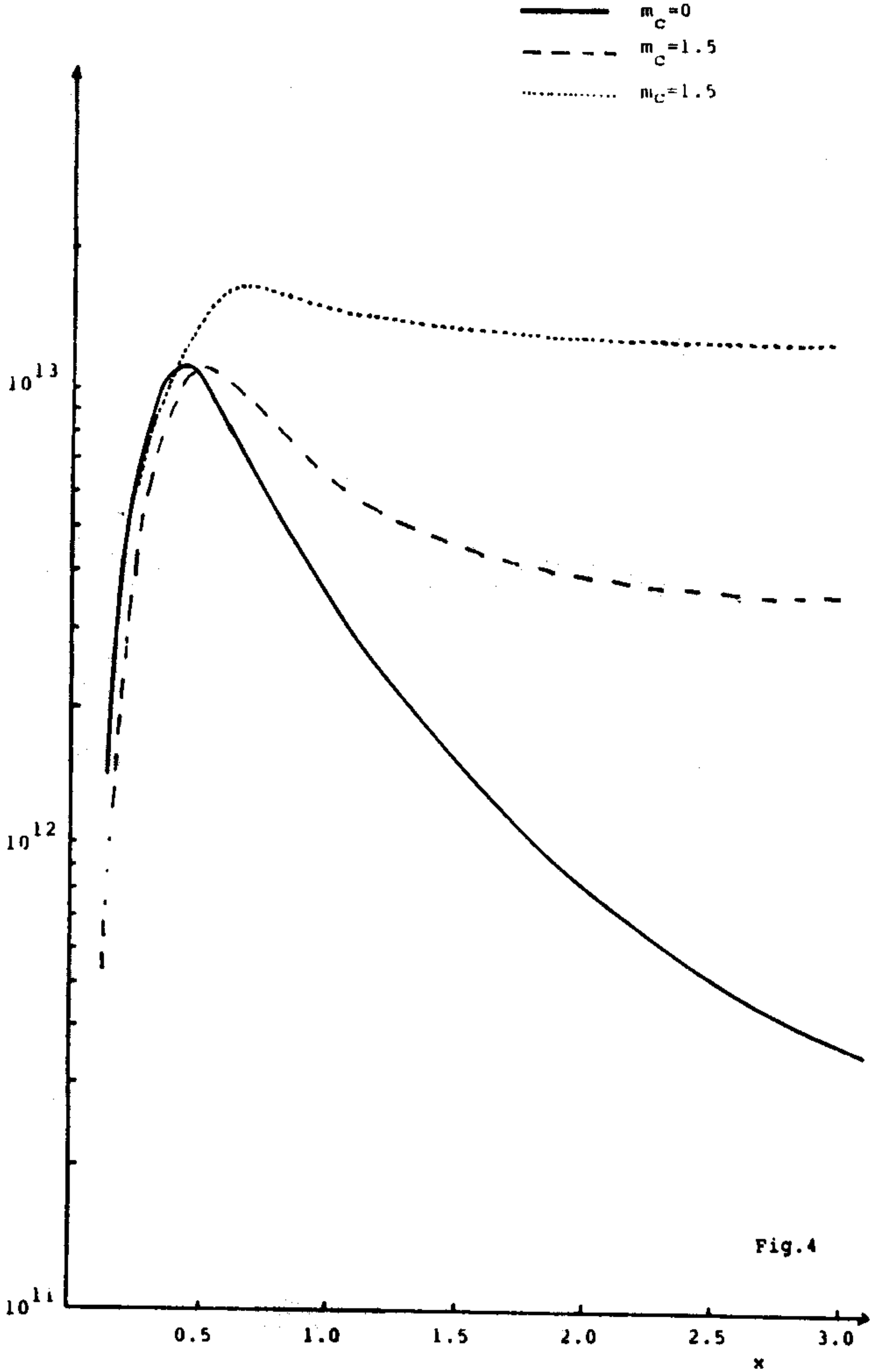


Fig.4

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