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ABSTRACT

A compound quark picture is suggested to explain the exponentially rising mass spectrum of the heavier vector mesons.

One of the more intriguing characteristics of the upsilon meson is its large mass.[1] The sequence of masses of the ϕ, ψ, Υ is growing exponentially. It is well fitted by the formula

$$m_n = m_\phi 3^{n-3}, \tag{1}$$

where n = 3 for the ϕ, 4 for the ψ, and 5 for the Υ. There is preliminary evidence that the mass of the vector meson associated with the t-quark will be greater than 15 GeV if a t quark exists.[2] (For convenience the quark associated with the upsilon is called the b quark here.) If one assumes that the masses of these vector mesons are due principally to their constituent quarks, this statement is equivalent to saying that the masses in the quark sequence strange, charm, and bottom are growing exponentially.

A spectral distribution of masses or energy levels is often a manifestation of a compound physical system. Atoms and hadrons composed of quarks are obvious examples. The periodic table also reflects this principle. Among the common compound physical systems none seem to produce an exponentially growing mass sequence.

While this possible mass sequence has been noted since the discovery of the upsilon, no explanations of it seem to have been advanced. There are many qualitative and usually phenomenological arguments for the mass of the charmed quark.[3] There have also been some suggestions for the mass value of the bottom quark.[4] These suggestions do not give an easy guide to the interrelation between quark masses. Instead, most theoretical work has been directed toward understanding the mass splittings of the meson systems.[5]

A simple picture seems capable of producing this mass spectrum. Consider a system formed of two quarks and an antiquark

$$q^* = qq\bar{q}. \qquad (2)$$

For convenience call q^* a compound quark and, for the moment, ignore questions of electric charge and the quark quantum number corresponding to s, c, or b. The compound quark can be formed to have the same spin, baryon number, and parity as its constituent quarks. Thus, in a sense, the compound quark is also a quark. If most of the mass of the compound quark is due to the constituent quark masses it will have approximately three times the mass of one of the constituents. In this picture, then, the compound quark related to charm would consist of quarks and an antiquark with the mass of a strange quark ($m_4 = 3m_3$) while the compound bottom quark would consist of the compound quarks related to charm ($m_5 = 3m_4$). This gives a quark mass formula

$$m_n^* = m_3^* 3^{n-1}, \qquad (3)$$

where m_n^* is the mass of the nth quark. Since meson mass splittings are on the order of 0.5 GeV, it is not surprising that this picture does not fit the masses of the lower mass vector mesons. The fit to the upper masses is surprisingly good, perhaps suggesting that an effect equivalent to saturation might set in.

If the picture is constrained by requiring that the charge on the c, s, and b quarks be compounded out of u and d quarks, the most rapidly rising mass sequence is

$$m_3 \approx 2m_u + m_d \tag{4}$$

$$m_4 \approx 5m_u + 2m_d \tag{5}$$

$$m_5 \approx 12m_u + 5m_d \tag{6}$$

$$m_6 \approx 29m_u + 12m_d \tag{7}$$

so that

$$m_n^{*'} \approx m_3 (2.4)^{n-3}. \tag{8}$$

This rises less rapidly than suggested by formula (3) because it is necessary to use $2\,q_{n-1}$ plus a q_{n-2} to get the necessary charge balance.

In this picture the higher quarks are regarded as compound objects. No inference has been drawn about the u and d quarks. Perhaps some natural way can be found in this picture to explain the quark quantum number and decay properties by relating it to the compound quark configuration. Compound quarks would presumably have structure. One should note that quarks are often regarded as point-like objects. Weight for this point of view is drawn largely from the success of the parton model.[6]

An obvious prediction of this picture is that the next vector meson will have roughly three times the mass of the upsilon, that is, 28 GeV. If this has any possibility of validity it is important to maintain the high energy luminosity on PETRA and PEP in order to search for vector mesons with masses near 30 GeV.

REFERENCES

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[2]C. Brown, private communication.

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[4]See, for example, R. M. Barnett, Phys. Rev. D15, 675 (1977). Note, however, that the emphasis of this discussion was influenced by the available data.

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