PHYSICAL REVIEW D VOLUME 43, NUMBER 11 1 JUNE 1991

# Heavy top quark and a possible Higgs mechanism

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(Received 22 October 1990)

The mass formula for the three lepton-quark generations derived in a left-right-symmetric composite model is reanalyzed by using the masses of the vector mesons ($\rho$, $\phi$, $K^*$, $D^*$, and $\Upsilon$). We obtain heavy-mass values between $m_t=170$ and 200 GeV. The Higgs mechanism with four Higgs mesons is briefly commented on as the background of the mass formula.

Several years ago a mass formula for the three generations of charged leptons and quarks ($l$-$q$ generations) was derived in a composite model for leptons ($l$), quarks ($q$), and Higgs mesons ($\phi$) based on the left-right-symmetric SU(3)-hypercolor interaction.[1] (For details of the composite model and the derivation of the mass formula, see Ref. 1.) From the mass formula the top-quark mass ($m_t$) is written in terms of other charged $l$-$q$ masses as[1]

$$m_t=\frac{1}{\Delta m_{sd}-\Delta m_{\mu e}}[m_b(\Delta m_{cu}-\Delta m_{\mu e})+m_\tau(\Delta m_{sd}-\Delta m_{cu})+m_\mu \Delta m_{du}+m_e\Delta m_{cs}+m_u m_s-m_d m_c]\ , \tag{1}$$

where $\Delta m_{ab}\equiv m_a-m_b$, and $(e,u,d)$, $(\mu,c,s)$, and $(\tau,t,b)$ for the three $l$-$q$ generations follow the ordinary notations. The formula is well approximated by

$$m_t=\frac{m_b(\Delta m_{cu}-\Delta m_{\mu e})+m_\tau(\Delta m_{sd}-\Delta m_{cu})}{\Delta m_{sd}-\Delta m_{\mu e}}\ . \tag{2}$$

In order to estimate $m_t$, the determination of the quark mass and mass differences, i.e., $m_b$, $\Delta m_{cu}$, and $\Delta m_{sd}$, is a most important and very ambiguous point. Among them, the determination of $\Delta m_{sd}$ in the denominator is the most crucial problem in the formula, because $\Delta m_{sd}$ and $\Delta m_{\mu e}$ are mutually comparable. In Ref. 1 $m_s=160$–$200$ MeV and $m_d=9$ MeV; that is, $\Delta m_{sd}\simeq 150$–$190$ MeV is used. Taking into account that the mass formula is quite sensitive to $\Delta m_{sd}$, these values do not seem to have a very reliable physical background and actually are a little larger than the values derived from the hadron mass spectrum. For instance, $\Delta m_{sd}$ is estimated by using the masses of the vector mesons[2] as follows:

$$\Delta m_{sd}\simeq\begin{cases} m_{K^*}-m_\rho\simeq 122\ \text{MeV}\ , & \text{(3a)}\\ \frac{1}{2}(m_\phi-m_\rho)\simeq 125\ \text{MeV}\ . & \text{(3b)}\end{cases}$$

In this brief note we shall reanalyze the top-quark mass by using only experimental hadron masses.

In order to evade the effects arising from spin-dependent forces, it is better to estimate $m_t$ only by using the masses of the hadrons belonging to the same hadron multiplet with a fixed spin. At present, the lowest vector-meson multiplet representing $\rho$, $\omega$, $\phi$, $K^*$, $D^*$, $J/\psi$, and $\Upsilon$, which already have the well-established masses, is only one possible candidate to estimate the parameters in (2), that is, $\Delta m_{sd}$, $\Delta m_{cu}$, and $m_b$. They are estimated as

$$\begin{aligned} &m_b\simeq\tfrac{1}{2}m_\Upsilon\simeq 4730\ \text{MeV}\ ,\\ &\Delta m_{cu}\simeq m_{D^*}-m_\rho\simeq 1240\ \text{MeV}\ ,\end{aligned} \tag{4}$$

and $\Delta m_{sd}$ is given in (3), where all hadron masses are from the data of the Particle Data Group.[2] Combining the values $\Delta m_{\mu e}=105$ MeV and $m_\tau=1784$ MeV, we have

$$m_t\simeq\begin{cases}200\ \text{GeV for (3a)}\ ,\\ 170\ \text{GeV for (3b)}\ .\end{cases} \tag{5}$$

This means that the mass of the lowest toponium ($t\bar t$ bound state) is estimated to be $m_{t\bar t}\simeq 340$–$400$ GeV. Taking account of the ambiguity in the estimation of $\Delta m_{sd}$, we may consider that $m_{t\bar t}\simeq 300$–$400$ GeV. The recent experiments which predict $m_t\gtrsim 100$ GeV seem to support these values. Of course, it would be too rash to say that the mass formula given in (2) is meaningful, much less than the model proposed in Ref. 1 is meaningful. It is, however, a bit interesting to note that the mass formula can be derived from the following Higgs couplings for the charged leptons and quarks:

$$\sum_i\sum_a(f_0^{(i)}\bar\psi_i^{(a)}\psi_i^{(a)}\phi_0+f_1^{(i)}\bar\psi_i^{(a)}\psi_i^{(a)}\phi^{(a)}+V^{(a)})\ , \tag{6}$$

where the summations over $i$ and $a$, respectively, stand for that for the $l$-$q$ generations and that for the three charged $l$-$q$ sectors in the $i$th generation, e.g., $a=(e,u,d)$ for the first generation. In (6) the four different Higgs mesons are introduced, that is, $\phi_0$, $\phi^{(l)}$, $\phi^{(u)}$, and $\phi^{(d)}$. The characteristic feature of (6) is represented by the fact that $\phi_0$ couples with all three $l$-$q$ sectors with *the same coupling constant* ($f_0^{(i)}$) and the three $\phi^{(a)}$ mesons, respectively, couple with the corresponding $l$-$q$ sectors with *the same coupling constant* ($f_1^{(i)}$), whereas in the standard model one or more Higgs mesons couple with all the $l$-$q$ sectors with *different coupling constants.* When all Higgs mesons have different vacuum expectation values, the mass generation mechanism is understood as follows: $\phi_0$ derives the same mass for all charged $l$-$q$ sectors in the same generation and the other three do the mass differences among them. In (6), $V^{(a)}$ may be considered to represent the effect of the QCD correction, which may be important only for the quark masses in the first generation. In general, the mass formula for the charged $l$-$q$ sectors in $i$th generation are obtained as

$$m_a^{(i)}=f_0^{(i)}\langle\phi_0\rangle+f_1^{(i)}\langle\phi^{(a)}\rangle+V^{(a)}\delta_{a,q}\ , \tag{7}$$

where $\langle\phi\rangle$ denotes the vacuum expectation value of the $\phi$ meson. Now the derivation of Eq. (1) is straightforward.[3]

The interesting point of this model is that in order to interpret the large mass of the $t$ quark, we do not need to introduce any large and unbalanced coupling constant of the $t$ quark with the Higgs mesons in comparison with those of the $b$ quark and the $\tau$ lepton. The introduction of the four different Higgs mesons seems to be too much. Taking into account that we have not yet had any experimental information about the Higgs mechanism, this scheme should not be excluded so easily. There are, of course, some problems with putting this Higgs mechanism into the standard model or some extended models and in determining the potential among the Higgs mesons for deriving desirable expectation values.

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[1]T. Kobayashi, Phys. Rev. D **31**, 2340 (1985). Also, see T. Kobayashi, Lett. Nuovo Cimento **44**, 97 (1984); Phys. Rev. D **33**, 2017 (1986); **34**, 3489 (1986).

[2]Particle Data Group, Phys. Lett. B **204**, 13 (1988).

[3]In order to derive (1), the following relations for two arbitrary generations ($i$ and $j$) are very useful:

$$m_1^{(1)}(m_2^{(j)}-m_l^{(j)})-(m_2^{(i)}-m_l^{(i)})m_1^{(j)}+m_2^{(i)}m_l^{(j)}-m_l^{(i)}m_2^{(j)}=0\ ,$$

where $m_1^{(i)}\equiv m_u^{(i)}-V^{(q)}$ and $m_2^{(i)}\equiv m_d^{(i)}-V^{(q)}$. It is noted that the above relations are written only by the masses of the $l$-$q$ sectors and $V^{(q)}$. Using the two relations among the three generations, we can eliminate $V^{(q)}$ and derive (1) (for details, see Ref. 1).