Low-energy supersymmetry and the decay $b \to s + H^0$

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The branching ratio for the decay $b \to s + H^0$ is calculated in supersymmetric models with a light H^0 boson. The value of $\mathrm{Br}(b \to s + H^0)$ turns out to be greatly suppressed in comparison with the prediction of the standard model. Most of the cancellation stems from an H^+ boson. The gluino-exchange component is negligible.

Relatively light neutral Higgs bosons occur in the decays of charmed particles, e.g., $\Upsilon \to H^0 + \gamma$, or, at $m_H \lesssim 5$ GeV, in B-meson decays $B \to H^0 + X$. From the theoretical standpoint, however, the smali mass of the scalar H bosons seems unnatural. The only argument in favor of light scalars may be the so-called close supersymmetry (SUSY). The superparticles, however, in addition to canceling the quadratic infinities in the masses of the H bosons, alter the amplitudes of processes which occur at the loop level. Among these processes are the decays $b \to s + H^0$. In the standard model their branching ratios turn out to be large if the t quark is heavy[1]:

$$Br(B \to H^0 + X) \approx 0.35\left(\frac{m_t}{80\ \mathrm{GeV}}\right)^4 \left(1 - \frac{m_H^2}{m_b^2}\right)^2, \qquad (1)$$

In this letter we calculate the amplitude for the decay $b \to s + H^0$ in a *SUSY* generalization of the standard model. We make use of the fact that in a minimal *SUSY* standard model the skeletal interactions of a sufficiently light H^0 boson are fixed: Within corrections on the order of m_H^2/m_Z^2, m_H^2/m_P^2 (m_P is the mass of a pseudosca-

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lar, and m_Z is the mass of the Z boson), the lightest H boson is the same as a combination σ_1 of neutral components of Higgs doublets φ_i:

$$\sigma_1 = \sqrt{2}(v_1 \mathrm{Re}\,\varphi_1^{(0)} + v_2 \mathrm{Re}\,\varphi_2^{(0)})/v \quad (v = (v_1^2 + v_2^2)^{1/2} = (G_F\sqrt{2})^{-1/2}),$$

which has skeletal interactions with all particles which are the same as those of an H^0 boson in the standard model. At the same accuracy level we also have $v_1 = v_2$ if the H boson is light.

To find the amplitude for the decay $b \to s + H^0$ we use a calculation technique for dealing with $b \to s$ transitions in an external Higgs field, ignoring the distinction between the H^0 boson and the state σ_1. The total amplitude is the sum of the diagrams in Fig. 1 which are reducible to single-particle diagrams and the "vertex" diagram in Fig. 1b which is not reducible in this fashion. If the "mass" operator $b \to s$ of the transition is of the form

$$\Sigma = (a + b\gamma_5) + (c + d\gamma_5)\hat{p},$$

the sum of the self-energy diagrams in Fig. 1a is (a, b, c, and d are assumed to be constants)

$$A_\Sigma = \frac{1}{v}\tilde{\Sigma} = \frac{1}{v}\bar{s}(a + b\gamma_5)b. \qquad (2)$$

The vertex $\Gamma(p_b, p_s, q)$ in Fig. 1b is calculated by differentiating with respect to the Higgs field and using the identity

$$\Gamma(p, p, q = 0) = -\frac{\partial}{\partial H}\Sigma(\hat{p}; H). \qquad (3)$$

It can be shown[2] that when (3) is extrapolated to a physical point, we find

$$\Gamma(p_b, p_s, q) = -\frac{\partial}{\partial H}\Sigma\left(\frac{p_b + p_s}{2}; H\right) + O\left(\frac{q^2}{m_t^2}, \frac{m_b^2}{m_W^2}\right). \qquad (4)$$

The SP invariance of the theory, for example, is sufficient for the validity of this expression.[2] As a result, the total amplitude A is

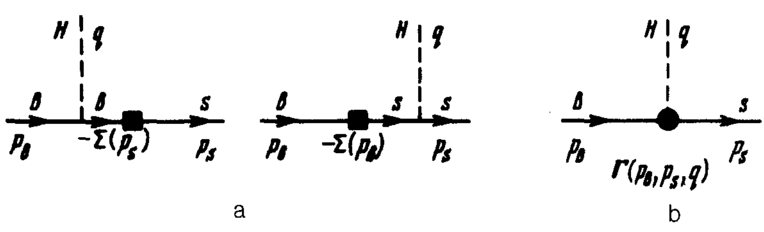

FIG. 1.

$$A = -\frac{1}{v}\bar{s}[v\frac{\partial}{\partial H}(a+b\gamma_5)-(a+b\gamma_5)+v\frac{\partial}{\partial H}(c+d\gamma_5)\frac{\hat{p}_b+\hat{p}_s}{2}]b. \quad (5)$$

In the standard model the particle masses m_i are proportional to the Higgs field, so we have $v\partial/\partial H = \Sigma_i(\partial/\partial \ln m_i)$. Since a and b have the dimensionality of a mass, while c and d are dimensionless, the amplitude A is determined exclusively by the anomalous dimensionalities of a, b, c, and d; i.e., it arises only by virtue of ultraviolet divergences in Σ. The calculation of the divergent part is elementary; it results in (1).

In a *SUSY* model the diagrams with an H^- boson and also with superparticles—a vino-higgsino and $\widetilde{T}$, $\widetilde{C}$ squarks—contribute along with the W^- exchange to $\Sigma_{b\to s}$. In the limit of a weakly broken *SUSY* ($M^2 \ll m_t^2$, m_W^2, where M^2 is the scale of the SUSY-breaking mass terms of the particles), the corresponding amplitudes are calculated as in the standard model: The H^- exchange gives us $A_{H^-} = -(5/3)A_0$, while the vino-higgsino exchange gives us $A_{SUSY} = -(2/3)A_0$ (A_0 is the amplitude in the standard model). In the *SUSY* limit we thus have

$$A = A_0 + A_{H^-} + A_{SUSY} = -4/3\, A_0. \quad (6)$$

At $M^2 \gg m_t^2$, m_W^2 A_H and A_{SUSY} tend toward zero; A_H remains negative, while A_{SUSY} can have either sign. Consequently pronounced cancellations are possible in reality. The calculations of A_{H^-} and A_{SUSY} in (5) must be carried out explicitly, with allowance for the nontrivial H dependence of the masses and also of the mixing angles (for the superparticles).

In realistic *SUSY-SUGRA* models, neutral superparticles (gluinos, zinos, etc.) may have interactions which are not diagonal in the superflavors,[3] so that their exchange can contribute to the decay $b \to s + H^0$. Gluino effects are potentialiy the most important, since they are proportional to $\alpha_s(m_{\tilde{g}}^2, m_{\tilde{Q}}^2)$. Analysis shows, however, that since the gluino propagator is independent of H in this approximation ($m_H^2 \ll m_P^2, m_Z^2$), the corresponding contribution to the amplitude $A_{\tilde{Z}}$ vanishes. The physical reason is the exact cancellation of the diagrams which are not reducible to single-particle diagrams and the vertex diagrams in Fig. 2 for the interaction with Higgs state σ_1. Only the zino-photino-higgsino exchanges may make a nonzero contribution, but such a contribution would die out not only in the limit of a strongly broken *SUSY* but also if the breaking is only slight. For this reason, this contribution to the amplitude $A_{\tilde{Z}}$ is always small.

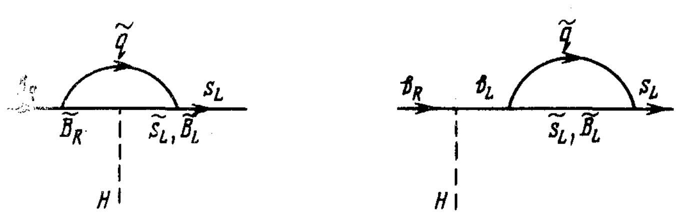

FIG. 2.

For some numerical estimates we have used the parameters found for the *SUSY* model through a solution of the renormalization-group equations from a scale $\sim 10^{16}$ GeV to $q^2 \sim m^2{}_W$. We selected the seed parameters in accordance with the condition $m^2{}_H \ll m^2{}_Z$; the condition $m^2{}_H \ll m^2{}_P$ turns out to be satisfied well at $m_H \lesssim 5$ GeV.

At $m_t \gtrsim 80$ GeV the scale of the *SUSY* breaking is small, and A_{H^-} turns out to be close to its *SUSY* value: $A_{H^-} \approx [(-1.3)-(-1.5)]A_0$. The contribution of the higgsino-vino, A_{H^-}, on the other hand, is greatly suppressed: $A_{H^-} \approx [(0.3)-(0.15)]A_0$. The contribution of neutral superparticles is no more than 1% in order of magnitude. As a result, the total bsH^0 amplitude A turns out to be slightly smaller than the standard amplitude A_0, and it has the opposite sign. The branching ratio is suppressed by a factor of 0.15–0.5 in comparison with the prediction of the standard model, (1). As m_t is reduced to 50–60 GeV, the scale of the *SUSY* breaking increases, with the result that there are even sharper cancellations in the amplitude.

The interval of H^0-boson masses, which are accessible to observation in B mesons, is slightly wider for the transitions $b \to d + H^0$. Their amplitude is found by replacing V_{ts} by V_{td} in the amplitude for $b \to s + H^0$. An analysis of the $B_d^0 - B_d^0$ mixing at $m_t \lesssim 100$ GeV leads to $|V_{td}| \gtrsim 0.4 |V_{ts}|$.

In summary, the branching ratio for H^0 production in the decays of b-hadrons is greatly suppressed in comparison with the standard model, and the experimental data available do not rule out the existence of a light H^0 boson of supersymmetric models.

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