K → π + LIGHT PSEUDOSCALAR

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The "classical" or "standard" axion now looks very dead and I feel no urge to try and revive it. I will however comment briefly on the present experimental situation,[1] and envisage the sensitivity of the more general decay K → π + light pseudoscalar, since such light particles might appear in a considerable number of models or theories (e.g.: supersymmetry, technicolor ...).[2]

For this purpose, I will consider two cases:

i) the tree-level coupling of the pseudoscalar h is flavor-diagonal (axion-type)

ii) the tree-level coupling is not flavor diagonal (flavor changing neutral current).

FLAVOR DIAGONAL TREE LEVEL COUPLING

The relevant part of the Lagrangian reads:

$$\frac{h}{2m_W} \Sigma \{m_i \; x \; \bar{u}_i\gamma_5 u_i + m_j \; y \; \bar{d}_j\gamma_5 d_j\} \qquad (1)$$

where

$$u_i = (u,c,t) \qquad d_j = (d,s,b)$$

The "standard" axion is described by: $|y| = |\frac{1}{x}|$; if <u>more</u> doublets are present, one usually has $|xy| > 1$. SU(2) × U(1) singlets with vacuum expectation values would allow $|xy| < 1$, but astrophysical data then imply $|xy| < 10^{-14}$, making earth-bound experiments somewhat hopeless.

The simplest and clearest way to see that the standard axion is now excluded is to consider the two branching ratios $B(\Upsilon\to h\gamma)$ and $B(\psi\to h\gamma)$. These tests are relatively clean because only the <u>direct</u> axion coupling to <u>heavy</u> quarks is involved, and the theoretical expectation is:

$$B(\Upsilon\to h\gamma)\; B(\psi\to h\gamma) \simeq (xy)^2 \frac{G_F^2 \; m_c^2 \; m_b^2}{2\pi^2 \; \alpha^2} B_{\mu\mu}(\psi)\cdot B_{\mu\mu}(\Upsilon) \simeq (xy)^2 \times 1.6 \times 10^{-8}$$

experimentally:[3]

$$\text{l.h.s.} < 0.9 \times 10^{-9} \text{ (90\% C.L.)} \qquad (2)$$

and this excludes the "standard" axion for "all values of x". Note the quotation marks around "all values of x". Indeed some care should be taken in view of the possibly non-neglibible mass of the axion for

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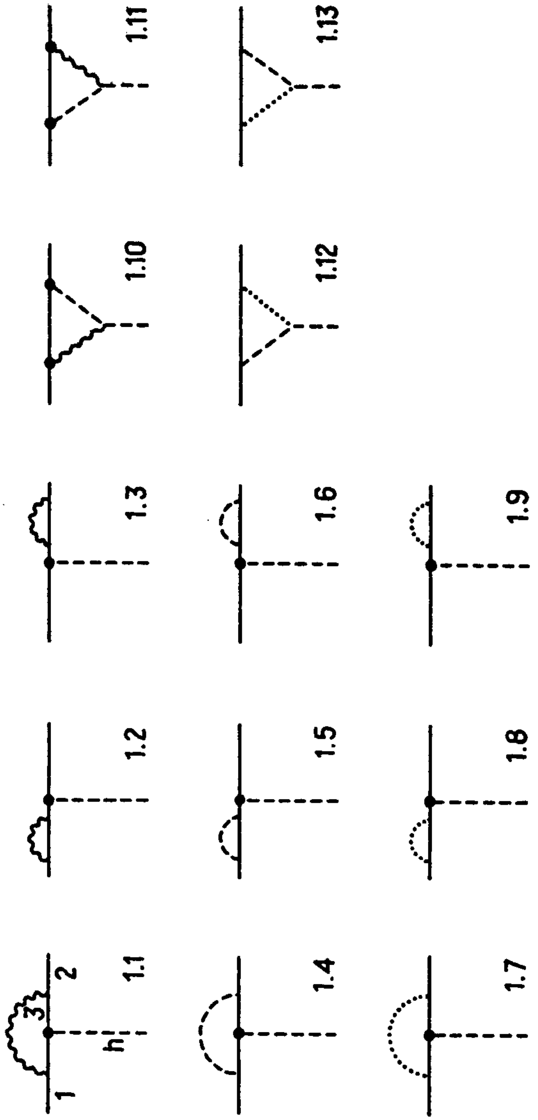

FIGURE 1

One-loop corrections to coupling of pseudoscalar (h) to quarks. (See Ref. 4.) The notation is: solid lines -- quarks; wavy lines -- gauge bosons; dashed lines -- pseudoscalar (h); and dotted lines -- charged scalar bosons ($H^{\pm}$).

x (or y) → ∞, since this mass obeys (for N families of quarks and leptons):

$$m_h \simeq N(x+y) \times 23 \text{ keV}. \qquad (3)$$

For large enough x or y, axions could then not be produced in ψ or T decays. It is however an easy matter to check that such values of x or y ($x \sim 10^5$ for $m \sim 1$ GeV) would not be compatible to a perturbative treatment of (1), therefore invalidating the whole approach.

If we want to depart from the relation $xy = 1$, with other possible models or light pseudoscalars in mind, we may ask the general question: How good are bounds on pseudoscalar couplings to quarks? From ψ decays alone, one gets typically $x < 1/\sqrt{50}$. How much better can we expect from K decays?

The rate of K decays into axion-like particles has been strongly debated in the past. Let us distinguish between "mixing" and "hard" contributions. The first contribution arises from mixing of the light pseudoscalars with the pions, etc., ... While the contribution due to pion mixing can be estimated from the $K \to \pi\pi$ decay, we have no direct experimental insight for $K \to \pi\eta$, which is kinematically forbidden. Further uncertainty arises from the applicability of the $(\Delta I = 3/2)/(\Delta I = 1/2)$ suppression to these processes and from the possible interferences. Therefore, estimates for the branching ratio vary from 10^{-6} to 10^{-8} according to the various authors (for $x \sim y \sim 1$).

A "hard" contribution arises at the one-loop level.[4] The naive W-exchange graph initially proposed has to be supplemented by 12 other diagrams, which bring into play one more unknown, namely the mass m_H of the charged spin-zero boson(s) associated with our light pseudoscalar (see Figure 1).

The branching ratio is then computed to be:

$$B(K\to\pi h) = 0.8 \times 10^{-6} \{x A_1 (m_c) + x^3 A_2 (m_c) + \left(\frac{m_t}{m_c}\right)^2 (S_2^2 + S_2 S_3) [x A_1(m_t) + x^3 A_2 (m_t)]\}^2 \qquad (4)$$

where the numerical values of the functions A_1 and A_2 are plotted in Figure 2.

Barring accidental cancellations, we see that, for $m_H \gtrsim 100$ GeV,

$$B(K\to\pi h) \sim 5\times10^{-4}\, x^2 \qquad (5)$$

which would provide a bound $|x| < 10^{-2}$ at the present experimental accuracy.

To close this section, we would like to conclude that K decays provide us with a very sensitive tool to explore light pseudoscalar couplings. However this tool suffers from two limitations: one is due to uncertainties arising from the understanding of "mixing" contributions, the other is linked to the unknown mass of charged "Higgs" bosons.

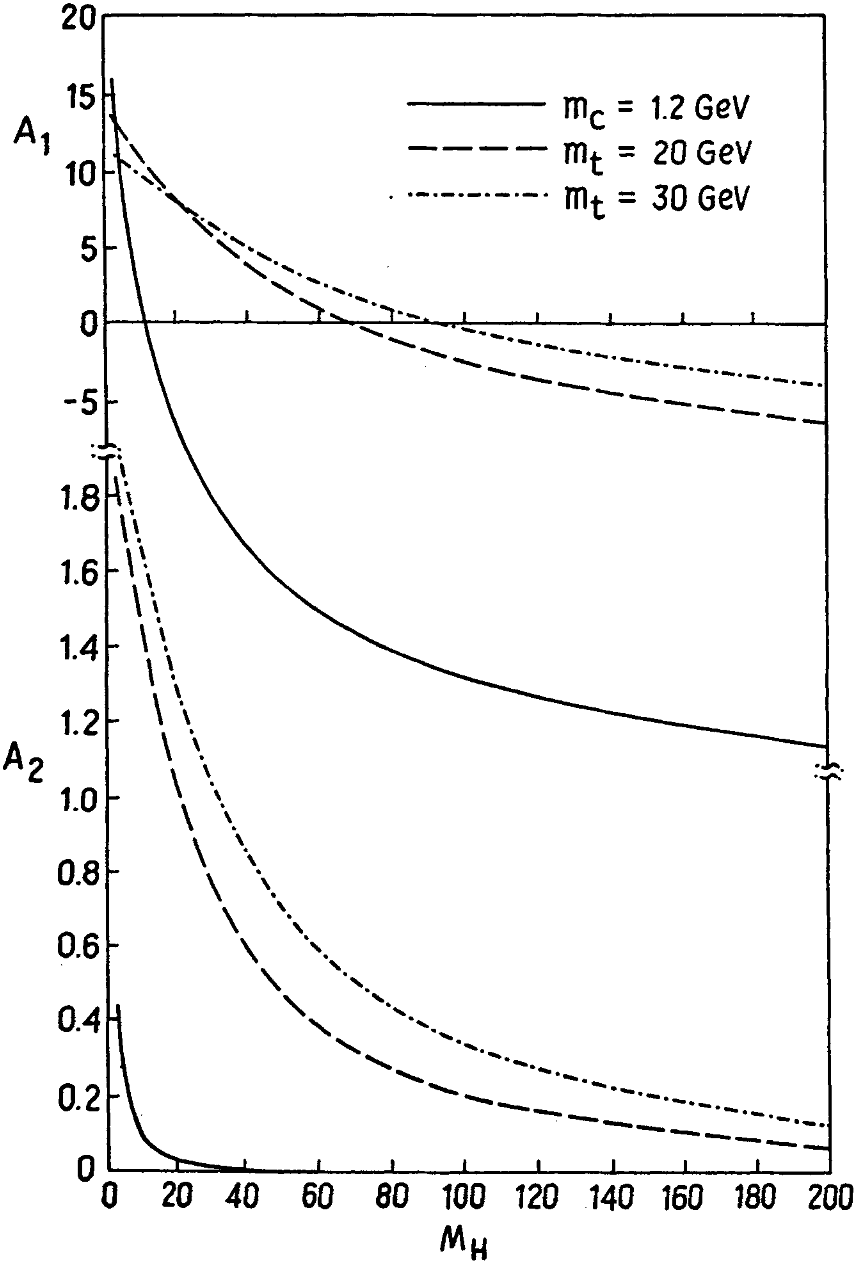

FIGURE 2

Numerical values of the functions A_1 and A_2 which determine B(K→πh) (see Eq. (4)).

The high sensitivity makes this tool quite unique, and places K decays in a prime position to establish the existence of such a coupling. Negative results unfortunately could most of the time be taken away be evoking (unlikely) cancellations between the various contributions.

FLAVOR NON-DIAGONAL COUPLINGS

We assume a "Goldstone" coupling of the kind (e.g. "familons",[5] technicolor, ...)

$$G\bar{s}\,\gamma_\mu\,\left(\frac{1-\gamma_5}{2}\right)\,d\,\partial^\mu h. \tag{6}$$

Limits on this coupling can be obtained somewhat indirectly and in a model dependent way (due to possible cancellations) from its contribution to the $K_L - K_S$ mass difference: one gets typically $G < 10^{-6}\ \mathrm{GeV}^{-1}$. Also, CP violation in K decays might be invoked; for an assumed phase of order one, we would get $|G| < 10^{-7.5}\ \mathrm{GeV}^{-1}$. Here we remark that $K \to \pi h$ fares much better since the limit derived from present experimental data gives:

$$G < 10^{-10}\ \mathrm{GeV}^{-1}.$$

(As an immediate consequence, such light bosons cannot be held responsible for CP violation!) Of course, the limits from $K\bar{K}$ mixing keep their value if h is too heavy to be produced in K decays.

REFERENCES

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