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Do Hyperphotons Exist?*

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The existence of the photon naturally suggests that there may also exist other "gauge" particles, coupled to other conserved currents.[1,2] This remained purely a speculation, until the recent appearance of experimental results[3] which seem to indicate a CP-violating $K_2^0 \rightarrow 2\pi$ decay.

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Independent letters by Bell and Perring[4] and by Bernstein, Cabibbo, and Lee[5] have pointed out that the effect observed can also be interpreted as the regeneration of K_1^0 by a new long-range interaction between the K-meson and our galaxy, which would have to act with opposite sign on the K^0 and $\bar{K}^0$ components. Both letters therefore suggest the existence of spin-one "hyperphotons" coupled to hypercharge (Y), or to Y plus some linear combination of Q and N. The purpose of this note is to argue on empirical grounds against the existence of such hyperphotons, and to indicate where to find them if they do exist.

The hypercharge current is not precisely conserved, so the hyperphoton must[6] have a small but finite mass m. But in all other respects it may be presumed to behave qualitatively like an ordinary photon. We can therefore calculate the matrix element for K^0 decay into two pions and a *soft* hyperphoton, of momentum q^μ (with $q^0 = \omega \equiv (|\underset{\sim}{q}|^2+m^2)^{1/2}$) and polarization ϵ^μ, as[7]

$$M(q,\epsilon) = \frac{fM}{(2\pi)^{3/2}(2\omega)^{1/2}} \; \frac{2P_K \cdot \epsilon}{(P_K-q)^2 + m_K^2} \tag{1}$$

where f is the coupling constant of K^0 to the soft hyperphoton, and M is the matrix element for $K^0 \to 2\pi$. The branching ratio for emission of hyperphotons of energy $\leq$ E in K^0 decay at rest is then

$$\frac{K^0 \to 2\pi + \text{"}\gamma\text{"}}{K^0 \to 2\pi} = \frac{f^2}{4\pi^2 m^2} \int_m^E \frac{(\omega^2-m^2)^{3/2}}{(\omega-m^2/2m_K)^2} \, d\omega \; . \tag{2}$$

This formula is *exact* for sufficiently small E and m (say, << 100 Mev) because then the matrix element is completely dominated by the pole term (1).[7] If we take E of order 100 Mev, and assume (quite safely) that $m \ll E$, then (2) becomes simply

$$\frac{K^0 \rightarrow 2\pi + \text{"}\gamma\text{"}}{K^0 \rightarrow 2\pi} \approx \frac{f^2 E^2}{8\pi^2 m^2} \; . \qquad (3)$$

The important point is that (3) depends only upon the ratio f^2/m^2, so *a very weak coupling can still give a large branching ratio if m is sufficiently small*. This circumstance can be traced back to the longitudinal term $q_\mu q_\nu/m^2$ in the polarization sum, which contributes here because K-decay violates hypercharge conservation. Similar conclusions would hold for any $\Delta S \neq 0$ decay process.

How large is f^2/m^2? The apparent $K_2^0 \rightarrow 2\pi$ decay rate can be explained by regeneraction of K_1^0 if the K^0 and $\bar{K}^0$ are split by the hyperphoton field by an amount $V \approx 10^{-8}$ ev. If hyperphotons interact purely with hypercharge then

$$V = f^2 \int d^3r \, n(\underset{\sim}{r}) \, e^{-mr}/4\pi r \qquad (4) .$$

where $n(\underset{\sim}{r})$ is the nucleon number density at position $\underset{\sim}{r}$ (with K-meson at $\underset{\sim}{r} = 0$). Hence f^2/m^2 must take the value

$$f^2/m^2 = V/\langle n \rangle \qquad (5)$$

where $\langle n \rangle$ is an effective density

$$\langle n \rangle = \int d^3\rho \, n(\underset{\sim}{\rho} m^{-1}) \, e^{-\rho}/4\pi\rho \; . \qquad (6)$$

If the range m^{-1} is larger than a galactic radius (as assumed by Bernstein, Cabibbo, and Lee) then

$$\langle n \rangle \cong n_C + n_G R_G^2 m^2 \tag{7}$$

where $n_C \cong 10^{-7}$ cm^{-3} is the average cosmic number density, $n_G \cong 4$ cm^{-3} is the average galactic number density, and $R_G \cong 6 \cdot 10^{22}$ cm is the effective galactic radius. Equation (7) holds only for $m^{-1} > R_G$, so we get the *smallest* value of f^2/m^2 if $m^{-1} \cong R_G$, in which case

$$f^2/m^2 \cong \langle V \rangle / n_G \cong 3 \cdot 10^{17} \text{ Mev}^{-2} \quad . \tag{8}$$

The branching ratio (3) for emission of hyperphotons with energy less than $E \approx 100$ Mev therefore takes the ridiculous value $4 \cdot 10^{19}$. If f^2/m^2 had the value (8) then not only the K-meson but all strange particles would be totally unstable.

The only way to avoid this catastrophe is[8] to take the range m^{-1} as less than the earth's radius (10^9 cm), so that $\langle n \rangle$ is about equal to half the terrestrial number density $n_E \cong 10^{24}/\text{cm}^3$, and

$$f^2/m^2 \cong 2\langle V \rangle / n_E \cong 2 \cdot 10^{-6} \text{ Mev}^{-2} \quad . \tag{9}$$

The branching ratio (3) now takes the acceptable value $2 \cdot 10^{-4}$. It is of course assumed here that m^{-1} is large enough (say $m^{-1} > 10^4$ cm) for the K-meson to feel the earth's field, and it seems rather artificial to suppose that m^{-1} falls conveniently in just that range $10^4 \text{ cm} < m^{-1} < 10^9$ cm for which K_1^0 regeneration is possible without huge branching ratios for hyperphoton emission. But perhaps a search for hyperphotons in $\Delta S \neq 0$ decays would be worthwhile.

It is interesting to ask what value might be expected a priori for the parameter f^2/m^2. If we suppose the hyperphoton mass to be given by the lowest-order self-energy diagrams, we may estimate[2]

$$m^2 \approx f^2 g_W{}^2 \mu^6$$

where $g_W = 10^{-5} m_p{}^{-2}$ is the weak coupling constant, and μ is some typical particle mass. The factor $g_W{}^2$ must appear, because the hyperphoton would presumably be massless were it not for the hypercharge-non-conserving weak interactions. [For instance, the diagram in which the hyperphoton dissociates into a $K \bar{K}$ pair does not contribute to m^2 unless we also add a hypercharge non-conserving bubble to one of the virtual K-meson lines.] Taking μ between 100 Mev and 1 Bev gives

$$f^2/m^2 \approx 10^4 \text{ to } 10^{10} \text{ Mev}^{-2} \quad . \tag{10}$$

This is in complete disagreement with either of our "empirical" estimates (8) or (9), and would in any case give an impossible value to the branching ratio (3) for hyperphoton emission.

Our conclusions are unaffected if the hyperphoton interacts with I_z instead of Y, and are even stronger if it interacts with S. In the latter case the nucleon coupling constant f_N to the hyperphoton field is less than the K-meson coupling constant f_K by a factor $g_W{}^2 \mu^4 \approx 10^{-10}$ to 10^{-14}, and since the "empirical" estimates (8) and (9) of f^2/m^2 must now be understood to refer to $f_N f_K/m^2$, we get values of $f_K{}^2/m^2$ which are larger than (8) or (9) by 10 to 14 orders of magnitude. This brings the "terrestrial" estimate (9) into good agreement with the *a priori* estimate (10), but of course it also gives a hopelessly large branching ratio for hyperphoton emission.

There is one other kind of argument which can be brought to bear against new particles of very small mass: a particle of mass $m < 1$ ev and with sufficient coupling strength to be stopped by the sun would have to be radiated by the sun according to the black-body laws, doubling the solar heat loss. This point does not apply to hyperphotons, since the sun would almost certainly be transparent to them, but it would apply to the quanta of Ne'eman's "fifth force"[2] if they had small enough mass.

I am very grateful for valuable discussions with R. Adair, J. Bell, W. Chinowsky, G. Feinberg, L. Leipuner, and J. Schultz.

REFERENCES

1. Vector bosons coupled to baryon number were suggested by E. P. Wigner, Proc. Nat'l. Acad. Sci. U.S. 38, 449 (1952). The difficulty of reconciling this suggestion with the Eotvos experiment was pointed out by T. D. Lee and C. N. Yang, Phys. Rev. 98, 101 (1955).
2. The possibility of vector bosons with very small mass coupled to the hypercharge or strangeness current was the subject of several illuminating discussions with G. Feinberg in 1959. Since then, similar particles were invoked by Y. Ne'eman, Phys. Rev. 134, B1355 (1964) to explain the breaking of SU_3 symmetry. Ne'eman's "fifth force" is rather strongly coupled to matter, and this leads to a number of contradictions with experiment, as discussed by D. Beder, R. Dashen, and S. Frautschi, to be published. Our main argument, and the astrophysical argument at the end of this Letter, can also both be applied to the fifth force, but our main argument has the advantage of applying even when the coupling constant is extremely small.
3. J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay, Phys. Rev. Letters 13, 138 (1964); A. Abashian, et al., Phys. Rev. Letters 13, 243 (1964). My own interest in the possible existence of gauge particles coupled to strangeness was revived by an earlier experiment by R. Adair et al., Phys. Rev. 132, 2285 (1963), which seemed to show an anomalous K_1^0 regeneration in liquid hydrogen, but which appears to be contradicted by the data of Christenson et al.
4. J. S. Bell and J. K. Perring, to be published in Phys. Rev. Letters.
5. J. Bernstein, N. Cabibbo, and T. D. Lee, to be published.
6. Coupling a massless spin-one particle (at zero momentum) to a non-conserved current would violate the Lorentz invariance of the S-matrix. S. Weinberg, Phys. Rev. 135, B1049 (1964).

7. The hyperphoton is emitted by the incoming K-meson line, this being the only term which becomes of order m^{-2} at low hyperphoton energy. Corresponding formulae are well known in electrodynamics; see, e.g., J. M. Jauch and F. Rohrlich, *Theory of Photons and Electrons* (Addison-Wesley, Reading, Mass., 1955), p. 392.

8. This was suggested to me by J. Bell. Using the earth as source means that the hyperphoton field is very anisotropic, so detection of this field in an Eotvös-type experiment[1] becomes possible in principle. The energy of a K-meson due to its interaction with the earth's field is 0.35 ev, while its hyperphoton potential energy is supposed to be about $0.5 \cdot 10^{-8}$ ev, so the ratio of the hyperphoton to gravitational *force* should also be $7 \cdot 10^{7}$. However, the hypercharge of ordinary matter is closely proportional to its inertial mass, the ratio varying by only 0.89% from hydrogen to iron; hence it would be necessary to look for differences in the apparent gravitational mass of about one part in 10^{10}.