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Author
Chanowitz, M.S.

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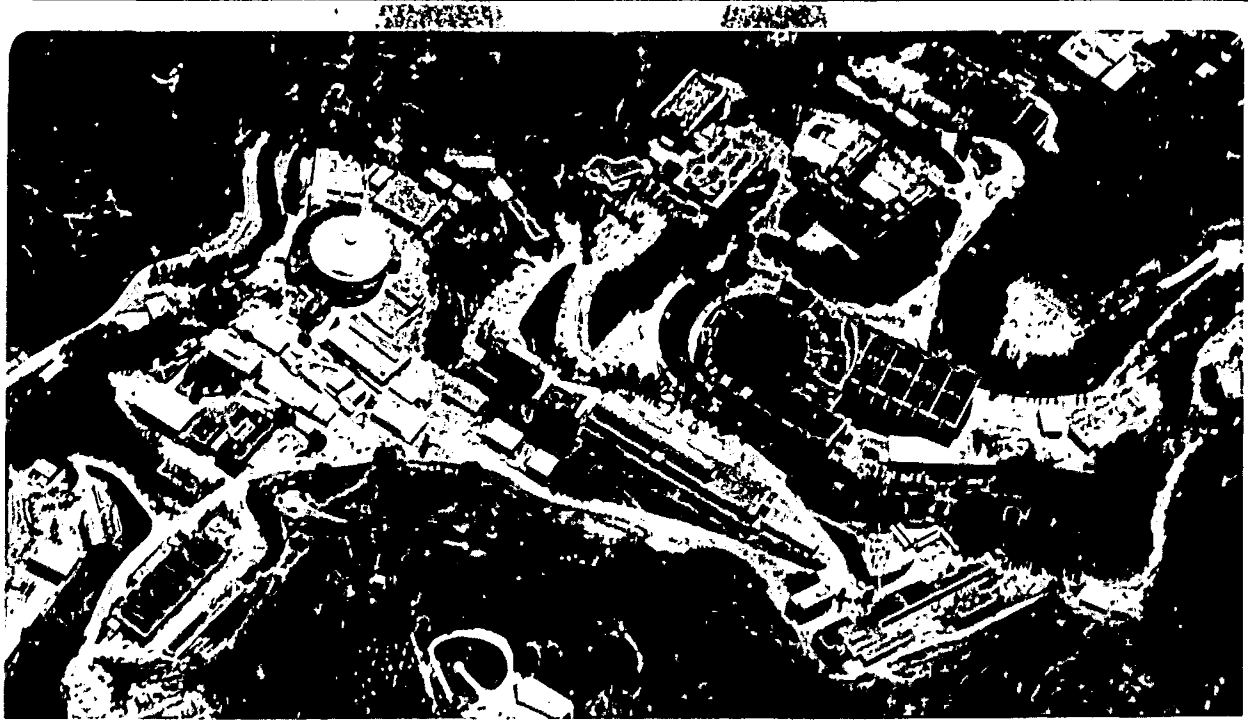

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Radiative Decays and SU(3) Flavor Structure of Iota(1460)*

Michael S. Chanowitz

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720, U.S.A.

Abstract

Relationships are derived between the iota(1460) partial widths to $\gamma\gamma$, $\rho\gamma$, $\omega\gamma$, and $\phi\gamma$. They can be used to test whether the reported $\rho\gamma$ enhancement is due to iota and to study the SU(3) flavor structure of iota decays.

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The purpose of this paper is to present relationships between radiative decays of the glueball candidate iota(1460) based on vector meson dominance[1] and SU(3) flavor symmetry. Using these relationships we can 1) test whether the $\rho\gamma$ enhancement[2] observed at 1420 MeV in $\psi \to \gamma\rho\gamma$ is due to $\psi \to \gamma\iota \to \gamma\rho\gamma$ and 2) determine the SU(3) flavor structure of the iota decay amplitudes. Besides $\rho\gamma$ the decay modes considered are $\gamma\gamma, \omega\gamma,$ and $\phi\gamma$, for which there are presently experimental upper bounds.[2,3] As a guide to the reliability of these relationships I conclude with a brief review of comparable relationships among $\rho \to \pi\gamma$, $\omega \to \pi\gamma$, $\phi \to \pi\gamma$ and $\pi \to \gamma\gamma$.

I want first to discuss the so-called "nonet symmetry" assumption – in fact not a symmetry at all but a dynamical hypothesis of equality for flavor singlet and octet amplitudes. Exact "nonet symmetry", or, perhaps more accurately, "singlet–octet equality", would imply equal singlet and octet wave functions, equal binding energies for singlet and octet, and therefore ideal mixing. The success of the OIZ rule[4] and ideal mixing for ρ, ω, and ϕ suggests that "1–8 equality" is an attractive hypothesis for the vector mesons, but the large deviations from ideal mixing in the pseudoscalar channel (the essence of the U(1) problems) mean that we must approach 1–8 equality for pseudoscalar amplitudes with caution. In the following analysis I will assume 1–8 equality for the vector channel but not the pseudoscalar.

We characterize the $\bar{q}q$ portion of the iota wave function by a mixing angle θ_ι,

$$\iota = \cos\theta_\iota \iota_1 + \sin\theta_\iota \iota_8 \tag{1}$$

Even if iota is predominantly a glueball we must allow for substantial $\theta_\iota \neq 0$ since the mixing with the $\bar{q}q$ sector may not be flavor symmetric. For instance, the predominance of $\iota \to \bar{K}K\pi$ could be a consequence of helicity enhancement for gg$\to \bar{s}s$ in the $J^P = 0^-$ channel.[5]

In terms of Lorentz scalar amplitudes $\mathcal{F}$ the partial widths are

$$\Gamma(\iota \to \gamma\gamma) = \frac{m_\iota^3}{64\pi} |\mathcal{F}(\iota \to \gamma\gamma)|^2 \tag{2}$$

$$\Gamma(\iota \to V\gamma) = \frac{(m_\iota^2 - m_V^2)^3}{32\pi m_\iota^3} |\mathcal{F}(\iota \to V\gamma)|^2 \tag{3}$$

and the vector meson dominance (VMD) approximation is

$$\mathcal{F}(\iota_a \to \gamma\gamma) = \sum_{V=\rho,\omega,\phi} \frac{e}{f_V} \mathcal{F}(\iota_a \to V\gamma). \tag{4}$$

From SU(3) symmetry and ideal mixing of $\omega - \phi$ it follows that $\mathcal{F}(\iota_1 \to V\gamma)$ are in the ratio $\rho : \omega : \phi = 1 : \frac{1}{3} : -\frac{\sqrt{2}}{3}$. The couplings e/f_V are in the same ratios using the same assumptions. For $\mathcal{F}(\iota_8 \to V\gamma)$ we must also invoke 1–8 equality for the vector mesons (but <u>not</u> for iota) to find the ratios $\rho : \omega : \phi = 1 : \frac{1}{3} : \frac{2\sqrt{2}}{3}$. The couplings f_V, determined from $f_V^2/4\pi = \alpha^2 m_V / 3\Gamma(V \to e^+e^-)$, are[6] $f_\rho^2/4\pi = 1.93 \pm .10$, $f_\omega^2/4\pi = 21.0 \pm 1.4$, and $f_\phi^2/4\pi = 13.8 \pm .6$. The SU(3) prediction for f_ρ^2/f_ω^2 is valid to 10% but disagrees by 25% for f_ρ^2/f_ϕ^2, as might be expected given the large $\phi - \rho$ mass difference. I will use the experimental values for the f_V^2 with phases taken from the SU(3) predictions.

I also include two corrections due to the large width of the rho meson. The first is purely kinematical: in place of eq. (3) which is valid for $\Gamma_V(TOT) << m_V$, we should calculate the process that is actually observed, $\iota \to \rho\gamma \to \pi\pi\gamma$, including a Breit-Wigner pole for ρ and computing the three body phase space. The result is a 20% correction of eq. (3),

$$\Gamma(\iota \to \rho\gamma \to \pi\,\pi\gamma) = (.80)\frac{(m_\iota^2 - m_\rho^2)^3}{32\pi m_\iota^3} |\mathcal{F}(\iota \to \rho\gamma|^2 \tag{5}$$

The analogous corrections for ω and ϕ are completely negligible. The second correction is to replace f_ρ by $f_{\rho\pi\pi}$, defined by $f_{\rho\pi\pi}^2/4\pi = 3m_\rho^2\Gamma_\rho/2k_\pi^3 = 2.97 \pm .10$. As shown by Yennie et al.[7] this prescription precisely accounts for the extrapolation from $p^2 = m_\rho^2$ where f_ρ is measured in $\rho \to e^+e^-$ to $p^2 = 0$ where it is applied in eq. (4).* For ω the analogous correction is negligible while for ϕ it may be significant though smaller than for ρ and more model dependent.[7] I shall take $f_\rho \to f_{\rho\pi\pi}$ in eq. (4) but leave f_ω and f_ϕ as measured in $\phi/\omega \to e^+e^-$.** While the two corrections, eq. (5) and $f_\rho \to f_{\rho\pi\pi}$, are each substantial, they tend to cancel and their net effect is to change the result, eq. (6) below, by only a few percent.

Finally we combine eqs.(1-5) and the assumptions discussed above to obtain the result

*The correction is cancelled in photoproduction but not in eq. (4). I thank D. Yennie for a discussion of this point

**Amusingly the experimental ratios $f_{\rho\pi\pi} : f_\omega : f_\phi$ are nearer the SU(3) prediction than $f_\rho : f_\omega : f_\phi$. Though possibly a fluke, this might reflect improved SU(3) symmetry for couplings all compared at $q^2 = 0$ rather than for q^2 from m_ρ^2 to m_ϕ^2.

$$\frac{\Gamma(\iota \to \gamma\gamma)}{\Gamma(\iota \to \rho\gamma \to \pi\pi\gamma)} = .625\left(1 - \frac{m_\rho^2}{m_\iota^2}\right)^3 \left(1.34\frac{e}{f_{\rho\pi\pi}}\right)^2 G(x)^2 \tag{6}$$

where

$$G(x) \equiv (1 + .51x)/(1 + x) \tag{7}$$

and the unknown parameter x is

$$x \equiv \tan\theta_\iota \cdot \frac{\mathcal{F}(\iota_8 \to \gamma\rho)}{\mathcal{F}(\iota_1 \to \gamma\rho)} \tag{8}$$

From the relations among the $\mathcal{F}(\iota_a \to V\gamma)$ given above we obtain two more predictions,

$$\Gamma(\iota \to \omega\gamma) = (.085)\Gamma(\iota \to \rho\gamma \to \pi\pi\gamma) \tag{9}$$

$$\Gamma(\iota \to \phi\gamma) = (.063)H(x)^2\Gamma(\iota \to \rho\gamma \to \pi\pi\gamma) \tag{10}$$

where

$$H(x) \equiv (1 - 2x)/(1 + x) \tag{11}$$

Equation (9) follows from $\mathcal{F}(\iota \to \rho\gamma) = 3\,\mathcal{F}(\iota \to \omega\gamma)$, a consequence of SU(3) symmetry and 1-8 equality for ϕ and ω. An analogous relation should hold regardless of the source of the $\rho\gamma$ enhancement. The present upper limit for the left side of eq. (9) is a factor 25 below the right side if the observed $\rho\gamma$ enhancement is identified with iota.[2]

Equations (6) and (10) give two constraints on x. If $\Gamma(\iota \to \gamma\gamma)/\Gamma(\iota \to \rho\gamma)$ and $\Gamma(\iota \to \phi\gamma)/\Gamma(\iota \to \rho\gamma)$ are measured, they determine x and test the reliability of this analysis. For the present, if we attribute the 1420 MeV $\rho\gamma$ enhancement to iota, eqs. (6) and (10) imply constraints on x that follow from the upper bounds on $\iota \to \gamma\gamma$ and $\iota \to \phi\gamma$. We define $\beta, \gamma, \delta, \epsilon$ by $B(\iota \to \bar{K}K\pi) > \beta$, $\Gamma(\iota \to \gamma\gamma) \cdot B(\iota \to \bar{K}K\pi) < \gamma$, $\Gamma(\iota \to \rho\gamma \to \pi\pi\gamma)/B(\iota \to \bar{K}K\pi) = \delta$ and $\Gamma(\iota \to \phi\gamma)/\Gamma(\iota \to \rho\gamma \to \pi\pi\gamma) < \epsilon$.

Then the constraints on x are

$$|G(x)| < \frac{11.7}{\beta}\sqrt{\frac{\gamma}{\delta}} \equiv G_0 \tag{12}$$

$$|H(x)| < 4.0\sqrt{\epsilon} \equiv H_0 \tag{13}$$

A plausible assessment of current data is $\beta = \frac{1}{2}$, since $\iota \to 4\pi$ only occurs significantly in $\rho\rho$ at[8] $\sim 40\%$ of $\bar{K}K\pi$ (which for our purposes we regard conservatively as an upper bond), $\eta\pi\pi$ is bounded[9] by $B(\iota \to \eta\pi\pi)/B(\iota \to \bar{K}K\pi) < .26$ (90% CL), leaving only $\eta'\pi\pi$ (which could be significant despite the small phase space) unaccounted. Presently the other values are[3] $\gamma = 2KeV$ and[2] $\epsilon = 1.6 \pm 0.4$, with the putative value[2] $\delta = 2.0\pm .75$ MeV. Then $G_0 = .74 \pm .14$, $H_0 = 5.1 \pm .6$, and eqs. (12) and (13) together yield the constraints $x \leq -2.0$ or $x \geq 1.1$.

This domain already excludes the hypothesis that iota decays like a flavor singlet, $\theta_\iota = 0 = x$. To get a feeling for the terrain in x, define $r = \sqrt{2}\,\mathcal{F}(\iota_8 \to \gamma\rho)/\mathcal{F}(\iota_1 \to \gamma\rho)$, which would equal unity if 1-8 equality held for iota. Then $x = r \tan \theta_\iota/\sqrt{2}$. If iota decayed like an $\bar{s}s$ state then $\tan\theta_\iota = -\sqrt{2}$ and $x = -r$. The above constraints would then imply $r < -1$ or $r > 2$. An educated guess is that r is likely to be positive and of order one, like the analogous quantity in η and η' decays.[10]

The constraints on x become very powerful if the experimental limits are improved so that G_0 is less than the asymptotic value of $|G| \to .5$ and H_0 less than $|H| \to 2$. From figure 1 we see that the first condition forces x to the neighborhood of $x = -2$ while the second forces it to $x = +\frac{1}{2}$. In fact, $G_0 < \frac{1}{2}$ implies $x < -1.5$ while $H_0 < 2$ implies $x > -.25$, two incompatible conditions. Our analysis would then be inconsistent with identification of the entire $\rho\gamma$ enhancement with iota. We can see from figure (1) that incompatible constraints are also possible when only one of the conditions $G_0 < \frac{1}{2}$ or $H_0 < 2$ are satisfied.

To gauge the reliability of this analysis, I have compared the analogous relationships for $\pi \to \gamma\gamma$, $\rho \to \pi\gamma$, $\omega \to \pi\gamma$ and $\phi \to \pi\gamma$ with present experimental data.[6] Using SU(3) symmetry, ideal mixing, and 1-8 equality for ω and ϕ, we predict $\mathcal{M}(\omega \to \pi\gamma) = 3\mathcal{M}(\rho \to \pi\gamma)$ or $\Gamma(\omega \to \pi\gamma)/\Gamma(\rho \to \pi\gamma) = 9.5$, within 2σ of the experimental value 12.2 ± 1.6. The prediction $\mathcal{M}(\phi \to \pi\gamma) = 0$ measures the deviation from ideal mixing and 1-8 equality. Using the measured value for $\Gamma(\phi \to \pi\gamma)/\Gamma(\omega \to \pi\gamma)$ the deviation from ideal mixing is at the 5% level in the amplitude, i.e., $\phi \sim \bar{s}s \pm .05(\bar{u}u + \bar{d}d)/\sqrt{2}$.

We test vector meson dominance with the relationship

$$\Gamma(\pi \to \gamma\gamma) = \frac{3\alpha}{16} m_\pi^3 \left\{ \sqrt{\frac{4\pi}{f_{\rho\pi\pi}^2} \frac{\Gamma(\rho \to \pi\gamma)}{k_\rho^3}} + \sqrt{\frac{4\pi}{f_\omega^2} \frac{\Gamma(\omega \to \pi\gamma)}{k_\omega^3}} \right\}^2 \tag{14}$$

In addition to vector meson dominance, eq. (14) assumes ideal mixing and singlet-octet equality for $\omega - \phi$, the SU(3) phase (but not the magnitude) for $f_\omega \mathcal{M}(\rho \to \pi\gamma)/f_\rho \mathcal{M}(\omega \to \pi\gamma)$, with the finite width correction $f_\rho \to f_{\rho\pi\pi}$ discussed above. Equation (14) yields $\Gamma(\pi \to \gamma\gamma) = 8.05 \pm .68$ eV, in excellent agreement with the data, $7.95 \pm .55$ eV[6] or $7.25 \pm .22$ eV.[11] Had we used the naive vector dominance relation with f_ρ rather than $f_{\rho\pi\pi}$, we would have found $9.84\pm .90$ eV, in significantly poorer agreement.

This suggests that the analysis of iota decays is reliable at the $\sim 25\%$ level, with the greatest uncertainty due to SU(3) symmetry breaking. If the limits on $\Gamma(\iota \to \gamma\gamma)/B(\iota \to \bar{K}K\pi)^2$ and $\Gamma(\iota \to \phi\gamma) \cdot B(\iota \to \bar{K}K\pi)$ are improved by factors of ~ 2 and ~ 6 respectively, with an added safety margin for the theoretical uncertainly, then $G_0 < \frac{1}{2}$ and $H_0 < 2$ and we could conclude that the $\rho\gamma$ enhancement cannot be fully attributable to iota. Further improvement in the experimental limits would exclude identification of an increasingly smaller fraction of the observed $\rho\gamma$ enhancement with iota. Within the limitations of the $\sim 25\%$ theoretical uncertainty, we can also use eqs. (6)-(11) to test the consistency of future measurements of the $\gamma\gamma$, $\rho\gamma$, $\omega\gamma$, and $\phi\gamma$ partial widths and to determine the flavor structure parameter x defined in eq. (8).

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Figure Caption

Figure 1. The functions G and H.

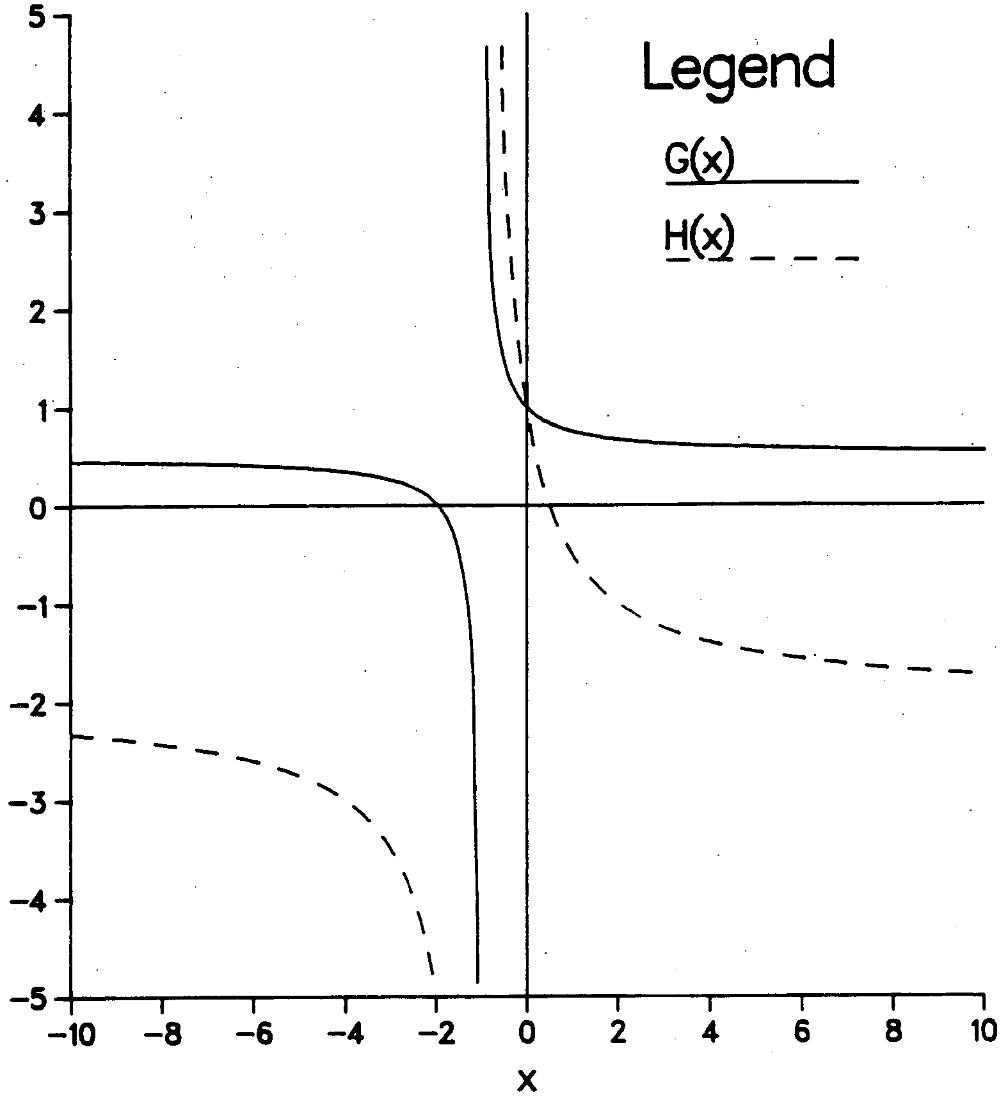

Figure 1

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720