RADIAL EXCITATIONS AND GLUEBALLS*

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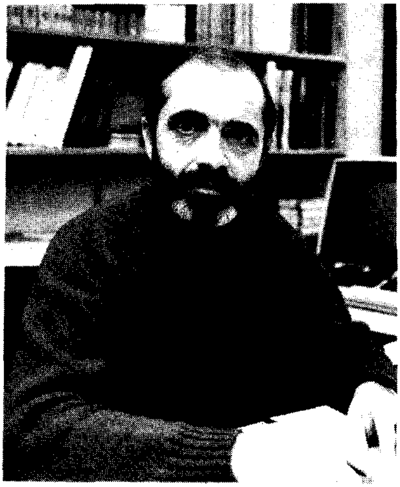

Abstract

An analysis of the light pseudoscalar and vector mesons predicts a number of new radial excited states together with their radiative decays. A measurement of some of these decay widths will give unambiguous evidence for the presence or absence of gluonium. A simple scaling of our solution to radiative ψ decays shows that it is not possible to account for the $\iota(1440)$ with only radial excited states but as a mixture of $q\bar{q}$ states and gluonium. Thus it is unlikely that pure gluonium states exist.

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**Talk presented by P.J. O'Donnell.

In this talk I am going to present results[1] of a large scale analysis of the light pseudoscalar ($^1S_0$) and vector mesons ($^3S_1$). The analysis follows and extends the procedure of earlier work[2] in which the existence of a radially excited π meson, about 1 GeV, and a radial excited η meson, about 1.4 GeV, were first predicted. Since then states with $J^{PC}=0^{-+}$ at these energies have been discovered although the favoured interpretation of the excited η meson has been that of a bound state of gluonium. However all of the tests for glueballs have not led to unique signatures and their existence remains uncertain.

In this present work we consider a system consisting of the ground state and the first two radial excited states of the mesons. Consequently there is a change in the traditional viewpoint of treating, for example, the pseudoscalar nonet as a system which has a mixing angle of -10^o or the vector mesons as one in which the ϕ is an ideally mixed $s\bar{s}$ state. Such a viewpoint should be considered as an approximation to the more complete scheme given here. In considering a set of three basis vectors out of which we form the physical states we are able to get a feeling for the error introduced by cutting off our previous analysis at one fewer state. The old results seem to be stable under the change of this cutoff and gives us reason to expect a similar stability for our more complete solution.

The calculation is as follows. We assume a non-relativistic harmonic oscillator potential to account for the ground and first two radial excited states. For s-waves this should not be a bad approximation due to the effect of boundary constraints at the origin and at infinity. Mixing among these states arises from a hyperfine-like interaction. We first fix some parameters by diagonalizing a 3x3 matrix for the π,ρ system and then obtain a similar result for the K,K* system involving only the strange quark mass as an additional parameter. It is interesting to note that the constituent quark masses found here are essentially those found in the baryon spectroscopy. For the ω-ϕ sector the calculation is made more complicated by the presence of singlet-octet mixing and means that we must consider a 6x6 matrix. Since this could lead to a large number of parameters, we choose to simplify this mixing as much as possible. Finally in the η-η' sector we also have a 6x6 matrix to consider. Because of the interest in, and ambiguity of the nature of the $\iota(1440)$ we add also a seventh glueball to this sector. After diagonalising the 7x7 system we are then able to compare the results of including a glueball mixing with the ground and radial excited states.

The results of our analysis are shown in tables 1 and 2. These give a large set of new radiative decay widths for the radially excited states, some of which are shown in table 2. In addition, for a few such widths, namely $\rho_2 \to \eta_1' \gamma$, $\eta_2 \to \rho_1 \gamma$, $\eta_2 \to \omega_1 \gamma$ and $\eta_2 \to \phi_1 \gamma$ there exists for the first time an unambiguous test for the presence or absence of a bound state of gluonium. Furthermore, when we insert gluonium we predict that there should exist at least two other η-like states between 1 and 2 GeV.

Having found the structure of the physical states we are now able to use a simple scaling argument to consider the radiative ψ decays. These are shown below in table 3 both for the purely radial-excited meson case and for the case in which we include glueball mixing. We see that the purely radial-excited solution is ruled-out, since with no gluonium mixing, the branching ratio $\psi \to \eta_2 \gamma$ should be compared to the experimental result on the previous line.

This implies that the branching ratio to $K\bar{K}\pi$ is greater than 100%.

Summary and Conclusions:

1. The spectra of the light mesons and their radiative widths have been obtained in a model which includes radial mixing. New states are predicted and their radiative decay widths are given. None of these new widths have been measured to date.
2. From our knowledge of the structure of the physical states we are able to provide an unambiguous test for the presence of a gluonium bound state, namely a measurement of the decays of $\rho_2 \to \eta_1 \gamma$, $\eta_2 \to \rho_1 \gamma$, $\eta_2 \to \omega_1 \gamma$ and $\eta_2 \to \phi_1 \gamma$.
3. Given this structure of the physical states we can simply scale our solution to consider the radiative decays of the ψ. The solution which does not have a glueball admixture is ruled out. Conversely it is unlikely that a pure glueball state can exist, instead there will be mixing with radial excited states.
4. There will exist at least two further states between 1 GeV and 2 GeV in the isoscalar-pseudoscalar system.
5. The simple mixing ideas for the vector and pseudoscalar nonets should be viewed as approximations to the more complete mixing situation.

We would like to thank the organisers of the XIXth Rencontre de Moriond for the opportunity to present these results and for the stimulating and enjoyable meeting.

Table 1. Predictions of masses in GeV in brackets with experimental values from ref. 3

I=1 sector

π_1(.135)	.140	ρ_1(.766)	.770
π_2(1.10)	1.3	ρ_2(1.54)	1.6
π_3(1.92)	1.67	ρ_3(2.36)	?

I=1/2 sector

K_1(.513)	.497	K_1^*(.902)	.89
K_2(1.27)	1.47	K_2^*(1.6)	1.4
K_3(2.0)	2.07	K_3^*(2.3)	?

I=0 sector Without gluonium

pseudoscalars

η_1(.530)	.549	η_1'(.1.07)	.959
η_2(1.39)	1.2757	η_2'(2.50)	?
η_3(2.1)	?	η_3'(3.2)	?

vectors

ω_1(.768)	.783	ϕ_1(1.05)	1.02
ω_2(1.56)	1.67	ϕ_2(1.69)	1.68
ω_3(2.42)	?	ϕ_3(2.33)	?

With gluonium the shift in predicted masses are as shown here.

pseudoscalars with gluonium

η_1(.570)	.549	η_1'(.1.05)	.959
η_2(1.39)	1.2757	η_2'(2.1)	?
η_3(2.8)	?	η_3'(3.6)	?
G(1.50)	1.44		

Table 2. Predicted Radiative Decays for Radially Excited States

Decay Mode	Predicted width without gluonium (Kev)	Predicted width with gluonium (KeV)
$\rho_2 \to \eta_1 \gamma$	3718.5	3229.6
$\rho_2 \to \eta_2 \gamma$	127.7	134.7
$\rho_2 \to \eta'_1 \gamma$	98.6	50.4
$\omega_2 \to \eta_1 \gamma$	402.7	342.7
$\omega_2 \to \eta_2 \gamma$	10.6	12.1
$\omega_2 \to \eta'_1 \gamma$	29.7	18.8
$\phi_1 \to \eta'_1 \gamma$	.71	.59
$\phi_2 \to \eta'_1 \gamma$	77.2	62.7
$\phi_2 \to \eta_1 \gamma$	70.9	72.4
$\phi_2 \to \eta_2 \gamma$	73.1	63.1
$\eta_2 \to \rho_1 \gamma$	121.3	269.3
$\eta_2 \to \omega_1 \gamma$	9.2	.6
$\eta_2 \to \phi_1 \gamma$	5.4	12.9

Table 3. Production and Decay rates for the Iota.

Decay Mode	Results with gluonium mixing	Results without gluonium mixing	Experiment
$BR(\psi \to \eta' \gamma)$	$3.6 x 10^{-3}$	$3.6 x 10^{-3}$	$(3.6 \pm 0.5) x 10^{-3}$
$BR(\psi \to \eta \gamma)$	$.325 x 10^{-3}$	$1.66 x 10^{-3}$	$(0.86 \pm .09) x 10^{-3}$
$BR(\psi \to \iota \gamma)$	$9.22 x 10^{-3}$		$\frac{5.3 \pm 0.6 \pm 1.9}{B(\iota \to K\bar{K}\pi)} x 10^{-3}$
$BR(\psi \to \eta_2 \gamma)$	$.778 x 10^{-3}$	$.142 x 10^{-3}$	not seen in $K\bar{K}\pi$, or $\eta\pi\pi$
$\Gamma(\iota \to \rho \gamma)$	422.13 keV		$\frac{9.1 \pm 2.8 \pm 1.6}{B(\psi \to \iota \gamma)} x 10^{-5} \Gamma(\iota)$
$\Gamma(\iota \to \omega \gamma)$	54.45 keV		
$\Gamma(\iota \to \phi \gamma)$	39.50 keV		
$\Gamma(\iota \to \gamma \gamma)$	2.5 keV		

References

1. This talk is based on work presented by the authors in Phys. Lett. 133B 253 (1983) and Phys. Rev. D29, 921 (1984) where full details of the model and a complete set of references may be found. The discussion of our results for ψ decays is presented here for the first time.
2. R.H. Graham and P.J. O'Donnell, Phys. Rev. D19, 284 (1979).
3. Particle Data Group, Phys. Lett. 111B, 1 (1982).