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Hybrid Mesons and Glueballs
—Version I—

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Abstract

A survey is given of the predicted masses and decay modes of the hybrid mesons and glueballs. The glueballs are expected to decay preferentially through an intermediate step involving a hybrid meson.

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1 Introduction

This note describes the predicted characteristics of the mesons that cannot be classified as quarkonia. An unambiguous signature for this is the combination of flavors which lies outside that allowed for a quarkonium. The mesons belonging to this class are, for example, those with $J^{PC} = 1^{-+}$, 0^{--}, 0^{+-}, 2^{+-}, and 3^{-+}. There are several candidates with 1^{-+} involving light quarks, u and d. So far there exist no exotic candidates containing $s\bar{s}$ and $c\bar{c}$.

The flux-tube model gives the masses and partial widths of J^{PC}-exotic hybrid mesons; they are reproduced here using the notations described in the next section. The masses and the quantum numbers of the glueballs predicted by the flux-tube model are also given. They are expected to decay through an intermediate step involing a hybrid meson. Examples of quasi-two-body decay modes with one J^{PC}-exotic hybrid and one S-wave quarkonium are given in Tables. In addition, all possible decay modes of glueballs which involve S- and P-wave quarkonia as the decay products, have been worked out.

2 Nomenclature

Before describing the characteristics of the J^{PC}-exotic mesons and glueballs, it is first necessary to comment on the notations which one may employ to denote these states. The PDG advocates a naming scheme in which a new notation involving a caret be introduced[1]. However, one must point out that it is *not* necessary to introduce a new naming scheme; the present conventions for the nomenclature are sufficient for *all* possible J^{PC}-exotic mesons. Denoting particle names within parentheses preceded by exotic J^{PC}'s, one may write

$$\begin{array}{ll} 0^{--} & (\rho_0, \omega_0, \phi_0, \psi_0) \\ 0^{+-} & (b_0, h_0, h_0', h_{0c}) \\ 1^{-+} & (\pi_1, \eta_1, \eta_1', \eta_{1c}) \\ 2^{+-} & (b_2, h_2, h_2', h_{2c}) \\ 3^{-+} & (\pi_3, \eta_3, \eta_3', \eta_{3c}) \end{array} \tag{1}$$

and so on. Finally, we shall use the word 'quarkonium' for any $q\bar{q}$ system; however, it is convenient to give different names for each class of quark mass. Hence we use the word 'isospinium' to indicate $n\bar{n}$ where $n = u$ or d (these are the only quarks which impart strong isospin flavor to hadronic matter), 'strangeonium' for $s\bar{s}$ and 'charmonium' for $c\bar{c}$.

3 Flux-tube Model for Exotic Mesons

According to the flux-tube model of quarkonia[2][3][4], a J^{PC}-exotic hybrid should decay into a P-wave and an S-wave meson, i.e. its decay into two S-wave mesons is supressed. Thus, an isovector $J^{PC} = 1^{-+}$ $n\bar{n} + g$ is not likely to decay into, for example, $\eta\pi$, although its coupling is not expected to be zero[3]. The favored decay modes and their partial widths are given in Tables I, II (from N. Isgur, et al.[2]), and Tables Ia, IIa and III (from F. Close and P. Page[3], [4]). For a more recent calculation of the hybrid and conventional mesons, see T. Barnes, F. E. Close and E. S. Swabson [5].

It is seen that the predicted exotic isospinium ($n\bar{n}$), strangeonium and charmonium hybrids are very wide, typically 300 MeV or wider—with very few exceptions. We regard the predicted widths as a guide to the relative strength of various decay channels. Ultimately, the width of a resonance is determined from experiments, and the tables show the likely decay channels in which one may search for the exotics.

Tables IVa through IVf show masses and quantum numbers of the glueballs predicted by Isgur and Paton [6]. The 0^{++} mass is given as 1.52 GeV, consistent with that from the lattice study [7] (1550 ± 50 MeV)—see Table V. But the 2^{++} mass 2.84 GeV by Isgur and Paton is some 570 MeV higher than that from the lattice study (2270 ± 100 MeV). The decay modes and widths are not given by the authors, but they state that glueballs should decay via hybrid mesons. The decay modes with one J^{PC}-exotic hybrid plus an S-wave quarkonium are given in the Tables; we do not consider the intermediate steps involoving non-exotic hybrids, although there is no known selection rule which forbids such decay modes. Also listed are the quasi-two-body decay modes involving S- and P-wave quarkonia [1] [8], which were assumed to be as follows:

${}^{2S+1}L_J$	J^{PC}	$I=1$	$I=0$	$I=1/2$
${}^1S_0$	0^{-+}	π	η, η'	K
${}^3S_1$	1^{--}	ρ	ω, ϕ	$K^*(890)$
${}^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1(1380)$	$K_1(1270/1400)$
${}^3P_0$	0^{++}	$a_0(980)$	$f_0(980), f_0(1300)$	$K_0^*(1430)$
${}^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1510)$	$K_1(1270/1400)$
${}^3P_2$	2^{++}	$a_2(1320)$	$f_2(1270), f_2'(1525)$	$K_2^*(1430)$

One may note that $a_0(980)$ and $f_0(980)$ are frequently thought to be four-quark states $s\bar{s}n\bar{n}$ and hence do not belong to the ${}^3P_0$ quarkonium family; however, their decays can easily be detected experimentally and so the glueball decays into these states may be worth looking for. The isoscalars $h_1(1380)$, $f_0(1300)$, $f_1(1510)$, $f_2'(1525)$ are not included (in most cases) in the decay channels for Table IV, either because they represent a hidden $s\bar{s}$ decay channel—therfore supresssed—or because these states are not well established. The K_1 states belonging to ${}^1P_1$ and ${}^3P_1$ nonets are mixtures of the physical states $K_1(1270)$ and $K_1(1400)$.

It should be noted that the notion of a glueball as consisting of a single glue loop implies that the number of gluons involved is infinite, and the gluons are therefore soft. The resulting decay of a glueball should couple preferentially to isospinium ($n\bar{n}$) channels and *not* to strangeonium or charmonium final states. For a review of gluonic hadrons from a theorist's point of view, one is referred to that by F. Close [9].

4 Conculsions and future prospects

The BNL experiment E852 at the BNL Multiparticle Spectrometer aims to carry out a systematic search with capabilities to detect both charged and neutral particles. The collaboration took data in spring 1994 and expects to take more data in a 5-month run in 1995.

Experiments at LEAR have produced scalar and tensor glueball candidates, but so far they report no J^{PC}-exotic meson candidates. It is hoped that additional experiments at IHEP/Protvino, Fermilab and Beijing will produce complementary results on our continuing search for gluonic excitations of hadronic matter.

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TABLES

Table I. Exotic Isospinium Hybrids[a]

I^G J^{PC}	State	Decay Mode	L of Decay	Partial Width (MeV)
1^+ 0^{+-}	$b_0(1900)$	$\pi a_1(1260)$	P	800
		$\pi h_1(1170)$	P	100
		$\pi\pi(1300)$	S	900
0^- 0^{+-}	$h_0(1900)$	$\pi b_1(1235)$	P	250
1^- 1^{-+}	$\pi_1(1900)$	$\pi b_1(1235)$	S, D	100,30
		$\pi f_1(1285)$	S, D	30,20
0^+ 1^{-+}	$\eta_1(1900)$	$\pi a_1(1260)$	S, D	100,70
		$\pi\pi(1300)$	P	100
		$\bar{K}K_1(1400)$	S	$\sim$100
1^+ 2^{+-}	$b_2(1900)$	$\pi a_2(1320)$	P	450
		$\pi a_1(1260)$	P	100
		$\pi h_1(1170)$	P	150
0^- 2^{+-}	$h_2(1900)$	$\pi b_1(1235)$	P	500

[a] See Ref.[2].

Table Ia. Exotic Isospinium Hybrids[a]

I^G J^{PC}	State	Decay Mode	L of Decay	Partial Width (MeV)
1^+ 0^{+-}	$b_0(2000)$	$\pi a_1(1260)$	P	700
		$\pi h_1(1170)$	P	125
		$b_1(1235)\eta$	P	80
		$\bar{K}K_1(1270)$	P	600
		$\bar{K}K_1(1400)$	P	150
0^- 0^{+-}	$h_0(2000)$	$\pi b_1(1235)$	P	300
		$\eta h_1(1170)$	P	90
		$\bar{K}K_1(1270)$	P	600
		$\bar{K}K_1(1400)$	P	150
1^- 1^{-+}	$\pi_1(2000)$	$\pi b_1(1235)$	S, D	150,20
		$\pi f_1(1285)$	S, D	40,20
		$\eta a_1(1285)$	S	50
		$\bar{K}K_1(1270)$	S	20
		$\bar{K}K_1(1400)$	S	$\sim$125
0^+ 1^{-+}	$\eta_1(2000)$	$\pi a_1(1260)$	S, D	100,70
		$\eta f_1(1285)$	S	50
		$\bar{K}K_1(1270)$	S	20
		$\bar{K}K_1(1400)$	S	$\sim$125
1^+ 2^{+-}	$b_2(2000)$	$\pi a_2(1320)$	P	200
		$\pi a_1(1260)$	P	70
		$\pi h_1(1170)$	P	90
		$\eta b_1(1235)$	P	$\sim$15
0^- 2^{+-}	$h_2(2000)$	$\pi b_1(1235)$	P	250
		$\eta h_1(1170)$	P	30

[a] See Ref.[3].

Table II. Exotic Strangeonium Hybrids[a]

I^G J^{PC}	State[b]	Decay Mode	L of Decay	Partial Width (MeV)
0^- 0^{+-}	$h_0'(2100)$	$\bar{K}K_1(1270)$	P	800
		$\bar{K}K_1(1400)$	P	50
		$\bar{K}K(1460)$	S	800
0^+ 1^{-+}	$\eta_1'(2100)$	$\bar{K}K_1(1270)$	D	80
		$\bar{K}K_1(1400)$	S	250
		$\bar{K}K(1460)$	P	30
0^- 2^{+-}	$h_2'(2100)$	$\bar{K}K_2^*(1430)$	P	250
		$\bar{K}K_1(1400)$	P	200

[a] See Ref.[2].

[b] Primes indicate $s\bar{s}$ flavor.

Table IIa. Exotic Strangeonium Hybrids[a]

I^G J^{PC}	State[b]	Decay Mode	L of Decay	Partial Width (MeV)
0^- 0^{+-}	$h_0'(2250)$	$\bar{K}K_1(1270)$	P	400
		$\bar{K}K_1(1400)$	P	175
0^+ 1^{-+}	$\eta_1'(2150)$	$\bar{K}K_1(1270)$	S, D	40,60
		$\bar{K}K_1(1400)$	S	250
0^- 2^{+-}	$h_2'(2150)$	$\bar{K}K_2^*(1430)$	P	90
		$\bar{K}K_1(1270)$	P	30
		$\bar{K}K_1(1400)$	P	70

[a] See Ref.[3].

[b] Primes indicate $s\bar{s}$ flavor.

Table III. Exotic Charmonium Hybrids[a]

$I^G\ J^{PC}$	State[b]	Decay Mode	L of Decay	Partial Width (MeV)
$0^-\ 0^{+-}$	$h_{c0}(4300)$	$\bar{D}D_1(2420)$	P	150
		$\bar{D}D_1(2450)$	P	90
$0^+\ 1^{-+}$	$\eta_{c1}(4300)$	$\bar{D}D_1(2420)$	S, D	30,40
		$\bar{D}D_1(2450)$	S	300
$0^-\ 2^{+-}$	$h_{c2}(4300)$	$\bar{D}D_2^*(2460)$	P	40
		$\bar{D}D_1(2420)$	P	10
		$\bar{D}D_1(2450)$	P	40

[a] See Ref.[4].

[b] Subscripts c indicate $c\bar{c}$ flavor.

Table IVa. Glueballs[a]

$I^G\ J^{PC}$	State	Decay Mode	L of Decay
$0^+\ 0^{++}$	$f_0(1520)$	$\pi\pi$, $\eta\eta$, $\eta\eta'$, $K\bar{K}$	S
		$\rho\rho$	S, D
		$\pi a_1(1260)$	P
$0^-\ 1^{+-}$	$h_1(2250)$	$\pi b_0(1900)$	P
		$\pi b_2(1900)$	P, F
		$\pi\rho$, $\eta\omega$, $\eta'\omega$, $\bar{K}K^*(890)$	S, D
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K}K_1(1270)$	P
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270)$	P, F
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\phi f_2'(1525)$	P, F
		$\rho a_0(980)$, $\omega f_0(980)$	P
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$	S, D

[a] See Ref.[6].

Table IVb. Glueballs[a]

I^G J^{PC}	State[b]	Decay Mode	L of Decay
0^+ 0^{++}	$f_0(2750\text{–}2790)$	$\rho b_0(1900)$, $\omega h_0(1900)$	P
		$\rho b_2(1900)$, $\omega h_2(1900)$	P, F
		$\pi\pi$, $\eta\eta$, $\eta\eta'$, $K\bar{K}$	S
		$\rho\rho$, $\omega\omega$, $\phi\phi$, $\bar{K}^*(890)K^*(890)$	S, D
		$\rho b_1(1235)$, $\omega h_1(1170)$, $\bar{K}^*(890)K_1(1270/1400)$	P
		$a_0(980)a_0(980)$, $f_0(980)f_0(980)$	S
		$a_1(1260)a_1(1260)$, $f_1(1285)f_1(1285)$	S, D
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	S, D
		$b_1(1235)b_1(1235)$, $h_1(1170)h_1(1170)$	S, D
		$a_2(1320)a_2(1320)$, $f_2(1270)f_2(1270)$	S, D, G
		$\bar{K}_2^*(1430)K_2^*(1430)$, $f_2'(1525)f_2'(1525)$	S, D, G
		$\pi a_1(1260)$, $\eta f_1(1285)$, $\eta' f_1(1285)$	P
		$\bar{K}K_1(1270/1400)$	P
		$a_0(980)a_2(1320)$, $f_0(980)f_2(1270)$	D
		$a_1(1260)a_2(1320)$, $f_1(1285)f_2(1270)$	D
		$\bar{K}_1(1270/1400)K_2^*(1430)$	D
0^- 0^{+-}	$*\, h_0(2790)$	$\rho\pi_1(1900)$, $\omega\eta_1(1900)$	S, D
		$f_0(980)\omega$, $a_0(980)\rho$, $\bar{K}_1(1270/1400)K^*(890)$	P
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K}K_1(1270/1400)$	P
		$\rho a_0(980)$, $\omega f_0(980)$, $\bar{K}^*(890)K_0^*(1430)$	P
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	P
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$, $\phi f_2'(1525)$	P
		$b_1(1235)a_1(1260)$, $h_1(1170)f_1(1285)$	S, D
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	S, D
		$b_1(1235)a_2(1320)$, $h_1(1170)f_2(1270)$	D
		$\bar{K}_1(1270/1400)K_2^*(1430)$	D

[a] See Ref.[6].

[b] The J^{PC}-exotic glueballs are denoted with an asterisk.

Table IVc. Glueballs[a]

$I^G\ J^{PC}$	State[b]	Decay Mode	L of Decay
$0^+\ 0^{-+}$	$\eta(2790)$	$\pi\pi_1(1900)$, $\eta\eta_1(1900)$	P
		$\rho b_2(1900)$, $\omega h_2(1900)$	D
		$\pi a_0(980)$, $\eta f_0(980)$, $\eta' f_0(980)$, $\bar{K}K_0^*(1430)$	S
		$\rho\rho$, $\omega\omega$, $\phi\phi$, $\bar{K}^*(890)K^*(890)$	P
		$\rho b_1(1235)$, $\omega h_1(1170)$, $\bar{K}^*(890)K_1(1270/1400)$	S, D
		$a_1(1260)a_1(1260)$, $f_1(1285)f_1(1285)$	P
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	P
		$b_1(1235)b_1(1235)$, $h_1(1170)h_1(1170)$	P
		$a_2(1320)a_2(1320)$, $f_2(1270)f_2(1270)$	P, F
		$\bar{K}_2^*(1430)K_2^*(1430)$, $f_2'(1525)f_2'(1525)$	P, F
		$a_0(980)a_1(1260)$, $f_0(980)f_1(1285)$	P
		$\bar{K}_0^*(1430)K_1(1270/1400)$	P
		$a_1(1260)a_2(1320)$, $f_1(1285)f_2(1270)$	P, F
		$\bar{K}_1(1270/1400)K_2^*(1430)$	P, F
		$\pi a_2(1320)$, $\eta f_2(1270)$, $\bar{K}K_2^*(1430)$	D
$0^-\ 0^{--}$	$*\,\omega_0(2790)$	$\pi b_0(1900)$, $\eta h_0(1900)$	S
		$\pi b_2(1900)$, $\eta h_2(1900)$	D
		$\rho\pi_1(1900)$, $\omega\eta_1(1900)$	P
		$\pi\rho$, $\eta\omega$, $\eta'\omega$, $\bar{K}K^*(890)$	P
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	D
		$\rho a_2(3120)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$, $\phi f_2'(1525)$	D
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$, $\bar{K}_0^*(1430)K_1(1270)$	P
		$b_1(1235)a_1(1260)$, $h_1(1170)f_1(1285)$	P
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	P
		$b_1(1235)a_2(1320)$, $h_1(1170)f_2(1270)$	P
		$\bar{K}_1(1270/1400)K_2^*(1430)$	P

[a] See Ref.[6].

[b] The J^{PC}-exotic glueballs are denoted with an asterisk.

Table IVd. Glueballs[a]

$I^G\ J^{PC}$	State[b]	Decay Mode	L of Decay
$0^+\ 2^{++}$	$f_2(2840)$	$\pi\pi_1(1900)$, $\eta\eta_1(1900)$	D
		$\rho b_0(1900)$, $\omega h_0(1900)$	P, F
		$\rho b_2(1900)$, $\omega h_2(1900)$	P, F, H
		$\pi\pi$, $\eta\eta$, $\eta\eta'$, $\eta'\eta'$, $K\bar{K}$	D
		$\rho\rho$, $\omega\omega$, $\phi\phi$, $\bar{K}^*(890)K^*(890)$	S, D
		$\rho b_1(1235)$, $\omega h_1(1235)$, $\bar{K}^*(890)K_1(1270/1400)$	D
		$a_0(980)a_1(1260)$, $f_0(980)f_1(1285)$	D
		$\bar{K}_0^*(1430)K_1(1270/1400)$	D
		$\pi a_1(1260)$, $\eta f_1(1285)$, $\bar{K}K_1(1270/1400)$	P, F
		$\pi a_2(1320)$, $\eta f_2(1270)$, $\bar{K}K_2^*(1430)$	P, F
		$a_0(980)a_0(980)$, $f_0(980)f_0(980)$, $\bar{K}_0^*(1430)K_0^*(1430)$	S, D
		$a_1(1260)a_1(1260)$, $f_1(1285)f_1(1285)$	S, D, G
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	S, D, G
		$a_2(1320)a_2(1320)$, $f_2(1270)f_2(1270)$	S, D, G
		$\bar{K}_2^*(1430)K_2^*(1430)$, $f_2'(1525)f_2'(1525)$	S, D, G
		$b_1(1235)b_1(1235)$, $h_1(1235)h_1(1235)$	S, D, G
		$a_0(980)a_2(1320)$, $f_0(980)f_2(1270)$, $\bar{K}_0^*(1430)K_2^*(1430)$	S, D, G
		$a_1(1260)a_2(1320)$, $f_1(1285)f_2(1270)$	S, D, G
		$\bar{K}_1(1270/1400)K_2^*(1430)$	S, D, G
$0^-\ 2^{+-}$	$*\,h_2(2840)$	$\pi b_2(1900)$, $\eta h_2(1900)$	P, F
		$\rho\pi_1(1900)$, $\omega\eta_1(1900)$	P, F
		$\pi\rho$, $\eta\omega$, $\eta'\omega$, $\bar{K}K^*(890)$	D
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K}K_1(1270/1400)$	P
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$	D
		$\bar{K}_0^*(1430)K_1(1270/1400)$	D
		$\rho a_0(980)$, $\omega f_0(980)$, $\bar{K}^*(890)K_0^*(1430)$	P, F
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	P, F
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$, $\phi f_2'(1525)$	P, F, H
		$b_1(1235)a_1(1260)$, $h_1(1170)f_1(1285)$	S, D, G
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	S, D, G
		$b_1(1235)a_2(1320)$, $h_1(1170)f_2(1270)$	S, D, G
		$\bar{K}_1(1270/1400)K_2^*(1430)$	S, D, G

[a] See Ref.[6].

[b] The J^{PC}-exotic glueballs are denoted with an asterisk.

Table IVe. Glueballs[a]

I^G J^{PC}	State	Decay Mode	L of Decay
0^+ 2^{-+}	$\eta_2(2840)$	$\pi\pi_1(1900)$, $\eta\eta_1(1900)$	P, F
		$\rho b_0(1900)$, $\omega h_0(1900)$	D
		$\rho b_2(1900)$, $\omega h_2(1900)$	S, D, G
		$\pi a_0(980)$, $\eta f_0(980)$, $\eta' f_0(980)$, $\bar{K} K_0^*(1430)$	D
		$\rho\rho$, $\omega\omega$,$\phi\phi$, $\bar{K}^*(890)K^*(890)$	P
		$\rho b_1(1235)$, $\omega h_1(1170)$, $\bar{K}^*(890)K_1(1270/1400)$	S, D, G
		$a_1(1260)a_1(1260)$, $f_1(1285)f_1(1285)$	P, F
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	P, F
		$a_2(1320)a_2(1320)$, $f_2(1270)f_2(1270)$	P, F
		$\bar{K}_2^*(1430)K_2^*(1430)$, $f_2'(1525)f_2'(1525)$	P, F
		$a_0(980)a_1(1260)$, $f_0(980)f_1(1285)$	P
		$\bar{K}_0^*(1430)K_1(1270/1400)$	P
		$a_0(980)a_2(1320)$, $f_0(980)f_2(1270)$	P, F
		$\bar{K}_0^*(1430)K_2^*(1430)$	P, F
		$a_1(1260)a_2(1320)$, $f_1(1285)f_2(1270)$	P, F
		$\bar{K}_1(1270/1400)K_2^*(1430)$	P, F
		$\pi a_2(1320)$, $\eta f_2(1270)$, $\bar{K} K_2^*(1430)$	D, G
		$\pi a_1(1260)$, $\eta f_1(1285)$, $\eta' f_1(1285)$, $\bar{K} K_1(1270/1400)$	D
		$b_1(1235)b_1(1235)$, $h_1(1170)h_1(1170)$	P, F
0^- 2^{--}	$\omega_2(2840)$	$\pi b_0(1900)$, $\eta h_0(1900)$	D
		$\pi b_2(1900)$, $\eta h_2(1900)$	S, D
		$\rho\pi_1(1900)$, $\omega\eta_1(1900)$	P, F
		$\pi\rho$, $\eta\omega$, $\eta'\omega$, $\bar{K} K^*(890)$	P
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K} K_1(1270/1400)$	D
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$	P
		$\bar{K}_0^*(1430)K_1(1270/1400)$	P
		$\rho a_0(980)$, $\omega f_0(980)$, $\bar{K}^*(890)K_0^*(1430)$	D
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	S, D, G
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$, $\phi f_2'(1525)$	S, D, G
		$b_1(1235)a_1(1260)$, $h_1(1170)f_1(1285)$	P, F
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	P, F
		$b_1(1235)a_2(1320)$, $h_1(1170)f_2(1270)$	P, F, H
		$\bar{K}_1(1270/1400)K_2^*(1430)$	P, F, H

[a] See Ref.[6].

Table IVf. Glueballs[a]

I^G J^{PC}	State	Decay Mode	L of Decay
0^- 1^{+-}	$h_1(3250)$	$\pi b_0(1900)$, $\eta h_0(1900)$	P
		$\pi b_2(1900)$, $\eta h_2(1900)$	P, F
		$\rho \pi_1(1900)$, $\omega \eta_1(1900)$	S, D
		$\pi \rho$, $\eta\omega$, $\eta'\omega$, $\bar{K}K^*(890)$	S, D
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K}K_1(1270/1400)$	P
		$\rho a_0(980)$, $\omega f_0(980)$, $\bar{K}^*(890)K_0^*(1430)$	P
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	P
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$, $\phi f_2'(1525)$	P
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$	S, D
		$\bar{K}_0^*(1430)K_1(1270/1400)$	S, D
		$a_1(1260)b_1(1235)$, $f_1(1285)h_1(1170)$	S, D
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	S, D
		$a_2(1320)b_1(1235)$, $f_2(1270)h_1(1170)$	S, D, G
		$\bar{K}_2^*(1430)K_1(1270/1400)$	S, D, G
0^- 3^{+-}	$h_3(3250)$	$\pi b_0(1900)$, $\eta h_0(1900)$	F
		$\pi b_2(1900)$, $\eta h_2(1900)$	P, F, H
		$\rho \pi_1(1900)$, $\omega \eta_1(1900)$	D, G
		$\pi \rho$, $\eta\omega$, $\eta'\omega$, $\bar{K}K^*(890)$	D
		$\pi b_1(1235)$, $\eta h_1(1170)$, $\eta' h_1(1170)$, $\bar{K}K_1(1270/1400)$	F
		$\rho a_0(980)$, $\omega f_0(980)$, $\bar{K}^*(890)K_0^*(1430)$, $\phi f_2'(1525)$	F
		$\rho a_1(1260)$, $\omega f_1(1285)$, $\bar{K}^*(890)K_1(1270/1400)$	P, F, H
		$\rho a_2(1320)$, $\omega f_2(1270)$, $\bar{K}^*(890)K_2^*(1430)$	P, F, H
		$a_0(980)b_1(1235)$, $f_0(980)h_1(1170)$	D
		$\bar{K}_0^*(1430)K_1(1270/1400)$	D
		$a_1(1260)b_1(1235)$, $f_1(1285)h_1(1170)$	D, G
		$\bar{K}_1(1270/1400)K_1(1270/1400)$	D, G
		$a_2(1320)b_1(1235)$, $f_2(1270)h_1(1170)$	S, D, G
		$\bar{K}_2^*(1430)K_1(1270/1400)$	S, D, G

[a] See Ref.[6].

Table V. Glueballs[a]

$I^G\ J^{PC}$	Mass (MeV)
$0^+\ 0^{++}$	1550 ± 50
$0^+\ 2^{++}$	2270 ± 90
$0^+\ 3^{++}$	3920 ± 50
$0^+\ 1^{++}$	3960 ± 30
$0^+\ 0^{-+}$	2330 ± 30
$0^+\ 2^{-+}$	3010 ± 20
$0^-\ 1^{+-}$	2900 ± 30
$0^-\ 2^{+-}$	3890 ± 30
$0^-\ 2^{--}$	3940 ± 40
$0^-\ 1^{--}$	4360 ± 50

[a] See Ref.[7].